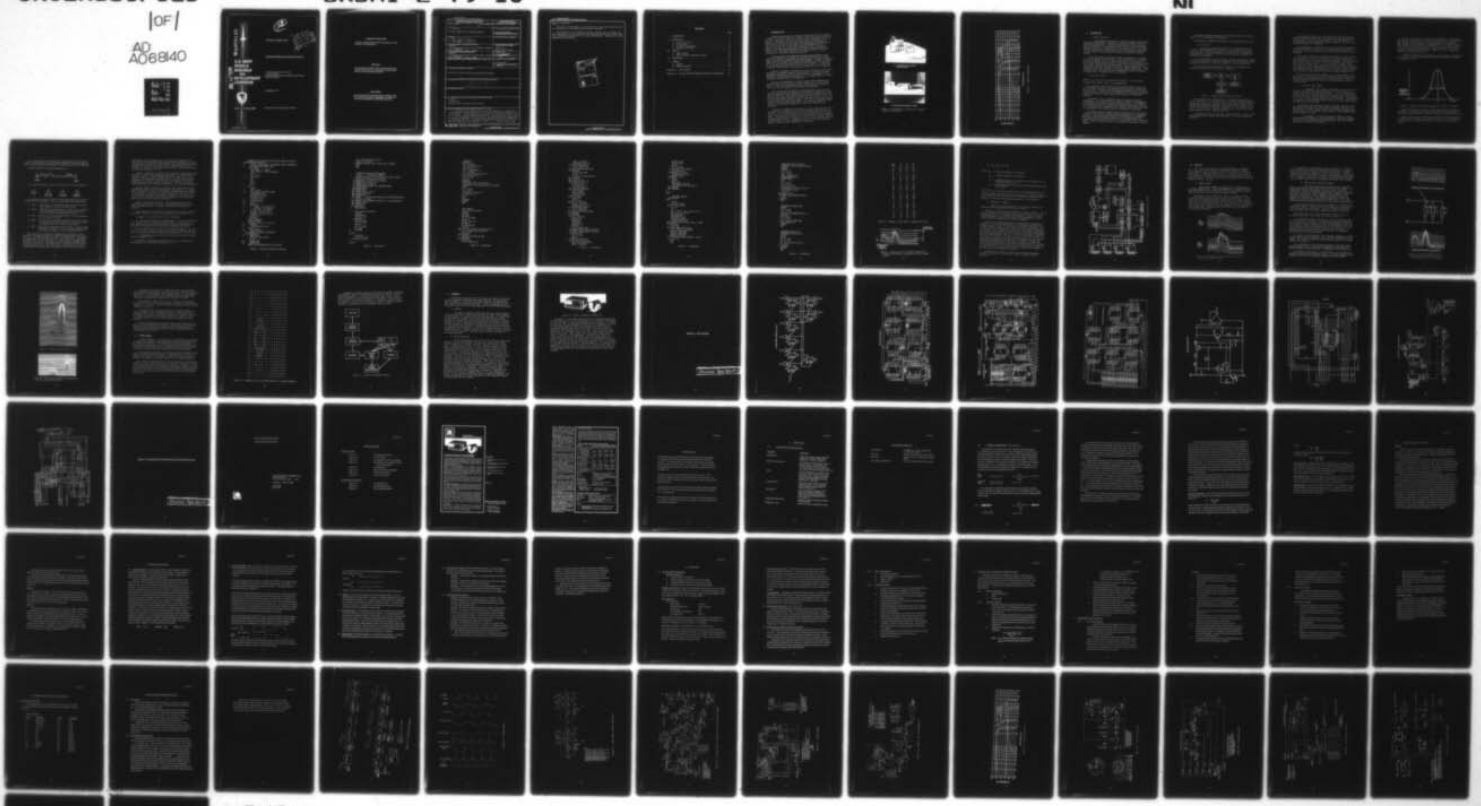
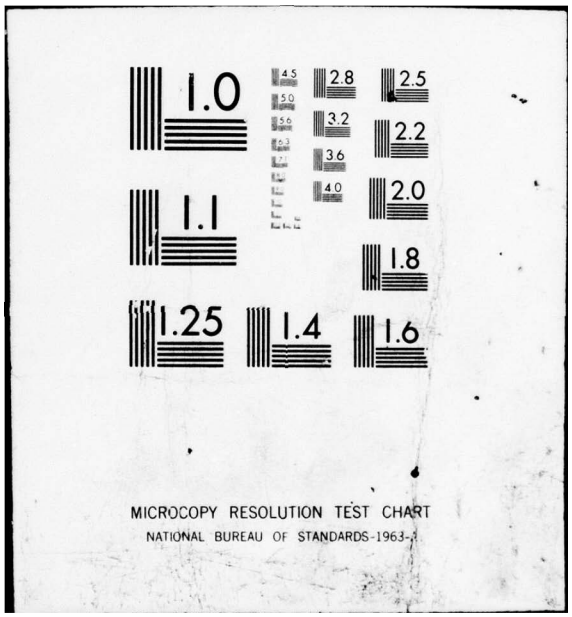
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TECHNICAL REPORT E-79-10

INFRARED INSPECTION OF PRINTED CIRCUITS

W. Tomme, Gordon D. Little, V. W. Ruwe,
and L. C. Layfield
Advanced Systems Development and Manufacturing Directorate
Engineering Laboratory

15 December 1978

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A system has been demonstrated to have the capability to identify and isolate printed circuit wiring board flaws which are presently undetected by existing means. The demonstration system uses an infrared sensor and a scanner to read the thermal characteristics of an operating printed wiring board. The thermal measurements are digitized and computer processed to compare the board's thermal map with a prerecorded standard. The fault location coordinates are read out by the computer. → next page Abstract (Continued)

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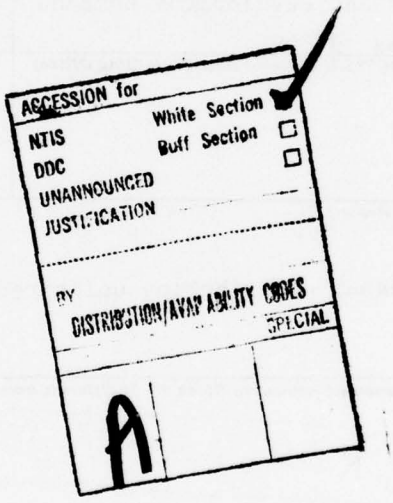
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Abstract (Concluded)

The system is applicable to a production test environment where multiple test stations can be accommodated by the data processor.

The selection of the appropriate sensors, scanner, data processor, and test algorithms have been optimized toward maximum sensitivity to fault detection, measurement repeatability, and cost effectiveness. Trade-offs of these parameters are discussed.



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I. INTRODUCTION

Printed wiring boards are presently being tested for the presence or absence of specific electrical signals at specified points within the circuits. Many flaws, such as poor solder joints, marginally good components, electrical overloads, circuit imbalances, and neglected or improper heat sinking are conditions that can degrade the components on the circuit board even though signals are within specifications. A number of devices fail in use due to undetected flaws. Structural damage to the printed wiring boards occur when operating temperatures are too high. The copper conductor path may pull, peel, or blister, resulting in a structural and electrical flaw.

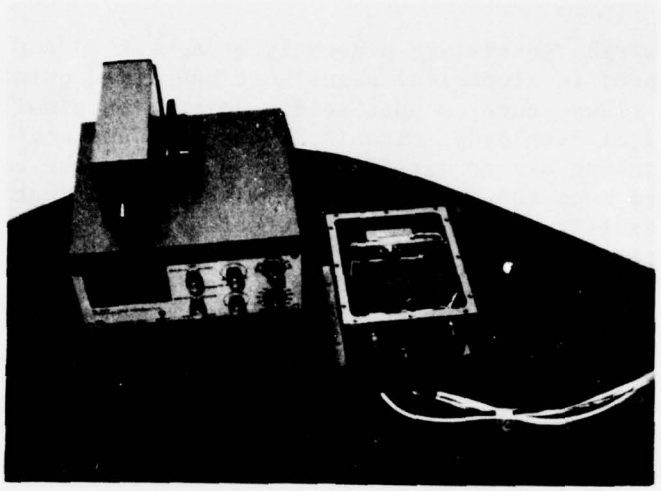
A testing process and equipment have been developed which demonstrate the capability to identify and isolate printed circuit wiring board flaws which are undetected by existing means. The process measures temperatures by infrared (IR) sensing and scanning to produce a thermal map of the printed wiring board during normal operation. A comparison of the thermal operating characteristics is then made to a prerecorded standard. The locations of the faults are then read out by a computer.

Studies of available IR sensors led to the selection of two devices possessing the minimum required characteristics. The Laser Precision Radiometer RK3440 was finally selected because of its superiority in measurement sensitivity and repeatability. Its sensitivity of 3°C above background radiation meets the design goal.

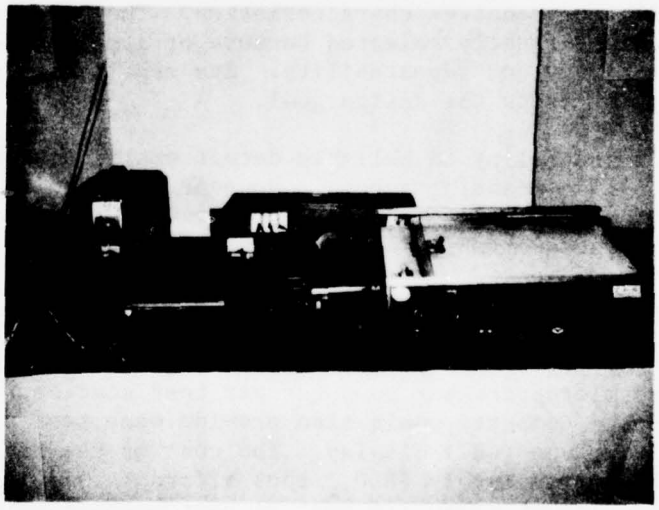
The system's capability to reliably detect small components was proved using a 16-line scanning scheme. However, due to its adverse impact on algorithm complexity, the 16-line scanner was discarded in favor of a 64-line scanner which was more cost effective.

The processor has the ability to interface with up to five test stations using standard encoding and any of several commerically available minicomputers. With appropriate interfacing, the system can fully operate using one microprocessor computer per test station. Use of the microprocessor-based computer would also provide each test station with its own cathode ray tube (CRT) display. The cost of the microprocessor computer would be approximately $800, thus affording significant cost savings by eliminating an expensive central host machine as the processor.

One aspect considered in the study, but not proved, was the use of the system on a microscopic level for use in inspecting hybird microcircuits. Such an application would be feasible by using an IR transparent lens in an optical device to allow an expansion of the apparent image. Caution would be needed due to the dilution of energy caused by the image magnification. Germanium or a similar lens material would be required with one fourth wavelength surfaces at the far IR spectrum. Figure 1 shows the major components of the system.



A. The RK3440 Sensor and Digital Acquisition System.



B. Scanner Board and Parallel X-Y Plotter.

Figure 1. Photographs of system used to inspect hybrid microcircuits.

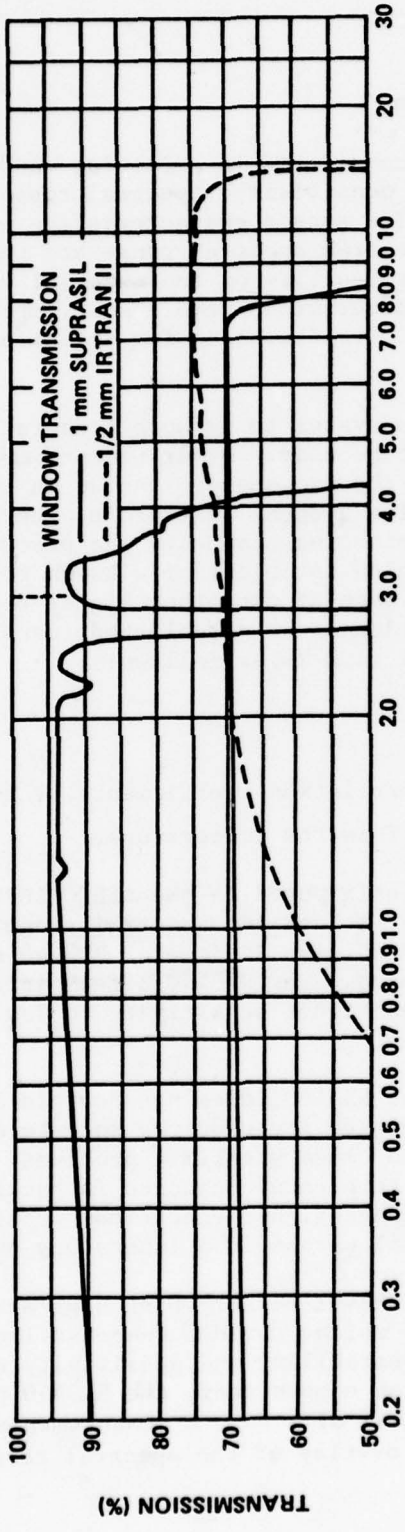


Figure 2. Window transmission.

II. DESCRIPTION

A. Sensor Selection

The parameters considered in selecting candidate sensors were measurement repeatability, sensitivity, spectral response, cost, and mechanical adaptability. The sensor characteristics which determine their performance in the desired spectral range are the active element material used and the transmissivity of the material used in the lens. The lens transmission characteristics were a most important parameter in that losses in the lens were the basis for rejection of several sensors.

To use the thermal map system to measure temperature, a standard of a known temperature must be used. Other factors must be considered in that the RK3440, one of the two sensors tested in the system, is basically an energy sensitive system. Therefore, the scanning spot must be no larger than the object being scanned. The procedure requires a calibration technique in which an object of a known temperature is first observed by the sensor and then at two other higher temperatures. This procedure allows a correlation to be established (usually a quadratic is sufficient). The normal form is as follows:

$$T = C_0 + C_1V + C_2V^2$$

where C_0, C_1, and C_2 are correlation coefficients, V is the output voltage of the system, and T is the temperature.

The germanium lens material used in the LEECO LCP200T sensor permitted adequate coverage in the desired spectral range, including most of the far IR. The Laser Precision Radiometer RK3440 uses an Irtran II lens and covers a similar band. The RK3440 offers increased performance in the far IR which provides higher sensitivity to low temperature radiation.

The LCP200T, unlike the RK3440, does not contain a built-in preamplifier. Its lower sensitivity requires an external preamplifier of gain sufficiently high to cause stability problems. The LCP200T is also adversely affected by temperature changes in background radiation. It is also sensitive to mechanical and electrical noise which may render its acceptability as marginal except in a laboratory environment.

The RK3440 employs a RKP3491 sensor which uses a Hall effect motor to drive an optical chopper which provides compensation for background radiation. Much higher repeatability and sensitivity are obtainable. With its background radiation compensator, the RK3440 permits the achievement of the design goal of 2 to 3°C measurements above background levels. Figure 2 shows an overlay of the spectral responses of the two sensors.

The window transmission response of the RKP3491 sensor is shown in Figure 2-7 of the appended specification.

The RKP3491 and RK3440 are described in the appended specification.

B. Scan System

A scanning system was developed to be compatible with both of the two sensors selected for testing. The scan system is of the line scan type. Thermal measurements are collected at a programmable rate along each scan line. The data are then digitized, encoded, and formatted for processing.

At the completion of each scan line, a retrace is executed. During retrace, execution data collection is blanked. The vertical step, which is manually selectable, is then incremented for the next scan line.

The interactive relationships of various system parameters and their effects upon scan rate is shown in Figure 3.

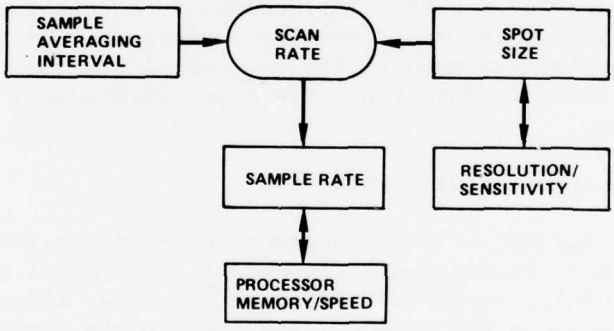


Figure 3. Parameters which affect scan rate.

The scanning rate is determined by the sample averaging interval and the sensor spot size (field-of-view). The sample averaging interval is the time interval, or distance of spot travel, over which a number of temperature samples were averaged to obtain one thermal reading. The system sample averaging intervals, selectable by a front panel control, are 0.1, 1, and 10 sec. Tests were generally run at the 0.1-sec averaging interval to allow a maximum scan rate.

A 4-mm spot size was the smallest field-of-view which could be used while maintaining the design goal sensitivity of 3°C above background radiation.

The averaging interval was 2 mm, which is to say that the next thermal reading was taken after the scanning spot had advanced a distance equal to one-half the spot diameter. At a sampling rate of 10 samples/sec, the scanning speed became 20 mm/sec. Thus, a 4 x 5-in. board is scanned in 6.77 minutes.

The sampling rate and 8-bit words do not tax the data acquisition system which operates at 4800 baud. A faster sampling rate would, obviously, increase the speed at which printed circuit boards could be evaluated.

The initial scanning system design was based on a 16-line resolution scheme which proved to be inadequate for reliable detection of 0.25-W resistors on a 4 x 5-in. printed wiring board. The 16-line system did, however, detect 0.25-W heat sources on smaller circuit boards. Also, on boards larger than 2 x 3 in. the 16-line scanning system required an extremely complex algorithm within the software. Although the complex algorithm development would be a one-time, nonrecurring cost, the resulting software, when implemented on a production basis, would require longer processing times, and therefore still greater costs.

The line spacing was also influenced, to a lesser degree, by the proper "spot" size which would provide coverage of the printed wiring board while maintaining sensitivity to thermal gradients. However, software algorithm complexity was the chief determinant of the line scanning system.

C. Processor Requirements

1. Hardware. The processor requirements for up to five test stations, for most production applications, can be met with any of several commercially available minicomputers. For this investigation, a PDP Eclipse using a NRZ encoded data link to the remote scan system was used. The data link was operated at a 4800-baud rate. The scanning of a 4 x 5-in. board required approximately 6.77 minutes. Time required to complete a scan would depend upon a selection of data samples/second and the selected line spacing.

The processor must have the ability to interface with up to five data links using an NRZ or similar standard encoding. The data are received on an interrupt basis, either as first level interrupt, buffered storage, or via an external signal system to advise each operator when the computer is busy.

2. Software. An extremely important element of the IR scanning inspection system is the application of the correct software in the form of algorithms and data conditioning. The test criteria govern the use and type of algorithm.

The data arrive from the data line in the form of a 7-bit binary word and is converted back to decimal in the processor. The sample rate, when running at maximum speed, is 1200 samples/sec. The software must consider various dispersion producing effects and include them in each decision made relative to the probability of error which exists at any spot on the printed wiring board. These false error sources can originate from environmental changes, digitizing errors, transmission errors, and component tolerances.

A Gaussian distribution is assumed to allow addition of the variance of each error although the component tolerance distribution is skewed by approximately 11%.

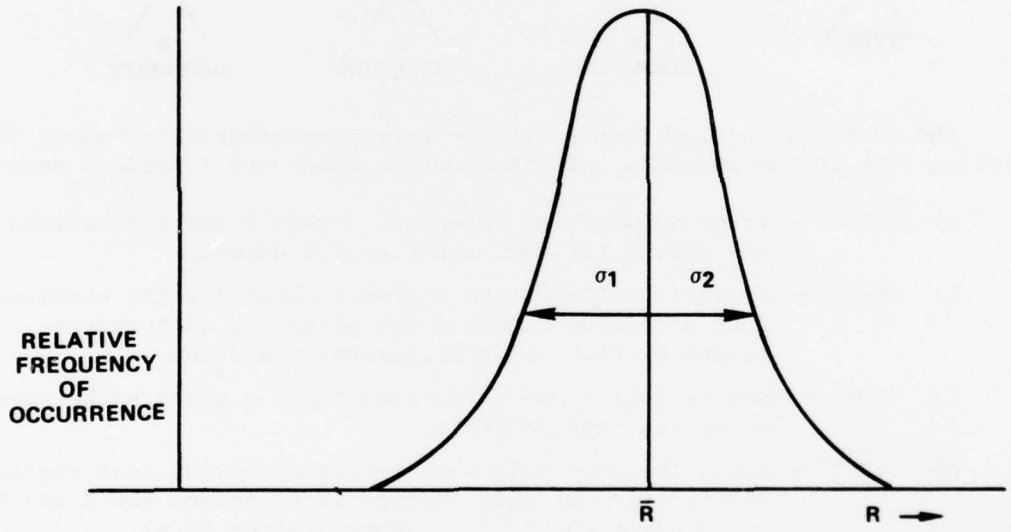


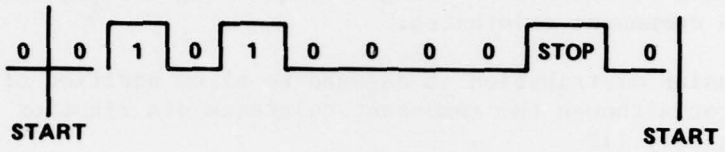
Figure 4. Shape of distribution produced by resistor tolerances.

After each sample is taken, the algorithms assess the validity of the sample. If the sample is valid, the second set of algorithms is applied to determine if the indicated radiation is normal for that point.

Many of the decision criteria are included in the supportive subroutines which are called by the executive routine. The routines must be fed the correct boundary conditions for the given circuit being tested.

The vital arbitrary constants must be determined for each circuit tested. The constants include allowable component tolerances, speed of scan, desired resolution, and amount of errors allowed in the data link.

The word format of the UART transmission is:



The format followed for each of the four words in a data sample is:



The subroutines used to support the executive program are shown in listing form in the appendix. The subroutine names and functions are:

a) DATAC — Forms a matrix of intensity versus X and Y locations, and checks for variance from the normal.

b) SCALE — Normalizes the entire matrix to best fit the standard, thus providing a method for adjusting differences caused by changes in background radiation.

c) SPOT — Used to locate any deviations above a given background set by the test criteria.

d) LEVEL — A routine used only when requested by the test station. The function of this routine is to define the X and Y coordinates whose IR is above a given level.

e) PUNT — The monitor routine which calls a halt to the test when input data are invalid. It also returns system control to the host processor and next requesting station.

When a data bit is missed, the reading will virtually be out of range and the algorithms flag the X and Y coordinates and the nature of the error. The fixed limits are loaded into the software. The sample is triggered by the sync word, and X, Y, and relative IR intensity are tested. If any are zero, negative, or greater than an assigned limit, the sample is rejected. The algorithms for comparison are then used to overlay the test matrix. The first step in this process is to scale the test matrix and summing all data points. The ratio of the two is

then used to scale the test matrix. If the ratio is greater than ±10%, then an error message is given instructing the operator to insert a normal board to reload the normal matrix. The algorithms then overlay the matrices, normalize, and then look for spot differences in the patterns. If they are out of the tolerance limits, the processor flags the location and degree of error.

Figure 5 illustrates a listing of the executive routine used by the processor to control the peripheral subroutines. The primary mode of operation used is to examine boards known to be faulty and to use the routines to define the most probable area of the faulty board, using temperature as a symptom. Other areas of abnormality are defined in descending order of the degree of abnormality. Further, the routine states the percentage of apparent dispersion at each located abnormality.

Figure 6 shows an optional listing and "word structure" for each sampled point along the line being scanned. The sampling of a single point transmits four words to the computer in binary NRZ and is decoded by the processor. The result is shown in Figure 6. The first word is a sync word signaling a data point, the next two are Y and X locations, and the last word is the measured radiation. This particular line is line 5 of the scan shown in Figure 7.

Several controls are available to the operator which include allowable variation, mode of search, limiting output to reflect only those temperatures above "x" degrees, and defining allowable data dropouts.

These controls are stored when the initial map is stored, but they may also be altered by use of an edit program at the processor site.

In summary, the algorithms perform the following:

a) Test each data point for reasonableness. If the value indicates that the data point is unreasonably high or low, it is considered a data dropout and a previous value obtained from the comparison map is inserted. The number of data dropouts is presented as an output.

b) The tested matrix is scaled in the following manner: the total of all IR values are summed for the normal matrix and then for the test map. The two maps are then compared for irregularities in the test map.

c) A "difference" map is produced and is used to estimate probable areas of component error.

The amount of dispersion allowed before an error is announced is determined by the sum of known variances; i.e.,

```
     DIMENSION C(64,64),CK(64,64),IRD(4),IAR(64,64),IRL(4)
C****PROGRAM NAME DDD ***
C       TO EDIT  AFTER MODS, DIR FORTRAN, FORT/L/D DPØ:DDD,
C       RLDR DPØ:DDD @LIBRARY. CM@
       CALL RESET
         CALL FOPEN (1, "$LPT")
         CALL OPEN (2,  "$TTI1",Ø,IER,1)
         K1=2
         DO 31 J=1,4
31       IRL (J)=1
         N=1
         K=Ø
         KC = 1
8        KP=Ø
       M=1
9        IRA=Ø
         DO 11 I=1,4
1Ø       CALL READR (2,Ø,IDAT,1,IER)
         IL=MOD(IDAT,25G)
         IR=(IDAT (IL)}/256
         IF(IRA)14,14,11
14       IF(IR)12,12,13
13       IF(IRA)1Ø,1Ø,11
12       IRA=1
11       IRD(I)=IR
         IF  (IRD(2). EQ. Ø) GO TO 9
17          IF(IRD(2). LE. 1Ø)KC=Ø
         IF  (KC. EQ. 1) GO TO 9
1Ø       IF(IRD(3). EQ. Ø) GO TO 9
         IF(IRD(4). EQ. Ø) TO TO 9
         M=IRD(3) 15
         N=IRD(2)
       IAR(M,N)=IRD(4)
       C(M,N)=IAR(M,N)
       IF(IRD(4) IRL(4) 1) 32,32,33
33       CONTINUE
32        IF(N.GT.5Ø) GO TO 22
       DO 3Ø J=1,4
3Ø       IRL(J)=IRD(J)
   16    WRITE(1,21)IRD(1),M,N,IRD(4)
   23 FORMAT(1914)
21       FORMAT(416)
         IF(M. EQ. 19) GO TO Ø
         GO TO 9
22       WRITE(1,6Ø)
6Ø       FORMAT(1H1)
       WRITE(1,23)((IAR(M,N),M=1,19),N=1,5Ø)
```

Figure 5. Executive program in Fortran.

```
      CALL DATAC(C,CK,OPTS,XE,YE)
      WRITE (12,65)XE,YE
   65 FORMAT(1H1,3HXE=,F1Ø,4,3HYE=,F1Ø.4) FORTRAN
      STOP
      END


      SUBROUTINE DATAC(C,CK,OPTS,XE,YE)
C  .... DATAC .... FORMS BASIC MATRIX
      DIMENSION E(64),C(64,64),D(64),X(64),R(64),SUM(64)
     1,CK(64,64),OPTS(15),XE(15),YE(15)
   5Ø FORMAT(E11.4,22X,2E11.4,15X,F1Ø.4)
   54 FORMAT(45X,I2,5X,E15.8)
   57 FORMAT(45X,I2,7X,E15.6)
   58 FORMAT(1HØ,44X,3HNO.,5X,12HCOEFFICIENTS)
   6Ø FORMAT(8F1Ø.4)
  5ØØ FORMAT(1ØI3)
  5Ø1 FORMAT(5(E12.4,3X),/)
  5Ø2 FORMAT(4X,8E14.5)
  5Ø3 FORMAT(8F10.4)
  5Ø4 FORMAT(    11X,6HY,DATA,8X,6HY,CALC,5X,9HDEVIATION,6X,
     114HX(1),X(2),ETC.)
  5Ø6 FORMAT( 43X,2ØHAVERAGE DEVIATION = F6.3,8H PERCENT)
  967 FORMAT(4F1Ø.4)
  968 FORMAT(4I4)
 1111 NK=OPTS(1)
      NDEV=OPTS(2)
C.....
      CALL PUNT(C,CK,OPTS(5))
      KPCH=Ø
      KPRT=OPTS(3)
      IF(NK)77,77,6
    6 NKP1=NK+1
      WRITE(12,5Ø7)
      DO 2 I=1,NKP1
      D(I)=Ø
      DO 2 J=1,NKP1
    2 C(I,J)=Ø
5     CONTINUE
C
C*****
      Y=C(II,JJ)
      DO 678 II=1,NK
  678 X(II)=C(II,JJ)
C
C*****
```

Figure 5. (Continued).

```
      IF(GO)7,3,3
    3 CONTINUE
      DO 4 J=2,NKP1
      C(1,J)=C(1,J)+X(J-1)
      C(J,1)=C(1,J)
      D(J) = D(J)+Y*X(J-1)
      DO 4 I=2,NKP1
    4 C(I,J)=C(I,J)+X(I-1)*X(J-1)
      C(1,1)=C(1,1)+ 1.Ø
      D(1) =D(1)+Y
      GO TO 5
    7 CONTINUE
      SUBROUTINE SPOT(C,CK,O,XE,YE)
      DIMENSION C(64,64),CK(64,64),O(15),XE,YE
      E1=Ø
      DO 1 J=1.64
      DO 1 I=1.64
      E2=ABS(C(I,J)-CK(I,J))
      IF (E2-E1)1,1,2
    2 XE=I
      YE=J
    1 CONTINUE
      RETURN
      END


C     SCALE MATRIX
      CALL SCALE(C,CK,OPTS)
      NT=NKP1
      NTP1=NT+1
      NTM1=NT-1
      DO 212 N=1,NTM1
      NP1=N+1
      DO 2Ø1 I=NP1,NT
      NTP=NT-N
      DO 2ØØ K=1,NTP
      J=NT-K+1
  2ØØ C(I,J)=C(I,N)*C(N,J)-C(N,N)*C(I,J)
      D(I)=C(I,N)*D(N)-C(N,N)*D(I)
      C(I,J-1)=Ø
  2Ø1 CONTINUE
      IF(C(NP1,NP1))2Ø3,2Ø4,2Ø3
  2Ø4 CONTINUE
      NP1P=NP1+1
      DO 211 IN=NP1P1,NT
```

Figure 5. (Continued).

```
      CLEAD = C(IN,NP1)
      IF(CLEAD)217,211,217
  217 D(IN)=D(IN)/CLEAD
      DO 216 JN=NP1P1,NT
  216 C(IN,JN)=C(IN,JN)/CLEAD
  211 CONTINUE
      DO 2Ø6 L=NP1,NTM1
      LP1=L+1
      IF(C(LP1,NP1))2Ø5,2Ø6,2Ø5
  2Ø6 CONTINUE
  2Ø5 DO 2Ø8 M=1,NT
  2Ø8 C(NTP1,M)=C(LP1,M)
      D(NTP1)=D(LP1)
      DO 2Ø9 M=1,NT
      C(LP1,M)=C(NP1,M)
  2Ø9 C(NP1,M)=C(NTP1,M)
      D(LP1)=D(NP1)
      D(NP1)=D(NTP1)
      DO 21Ø M=1,NTP1
  21Ø C(NTP1.M)=0
      D(NTP1)=Ø
      GO TO 212
  2Ø3 DO 213 IN=NP1,NT
      CLEAD = C(IN,NP1)
      IF(CLEAD)214,213,214
  214 D(IN)=D(IN)/CLEAD
      DO 215 JN=NP1,NT
  215 C(IN,JN)=C(IN,JN)/CLEAD
  213 CONTINUE
  212 CONTINUE
   14 DO 15 TAA=1,NT
      KA=NTP1-IAA
      SUM(KA)=Ø
      R(NTP1)=Ø
      C(KA,NTP1)=Ø
      MAA=KA+1
      DO 16 JA=MAA, NTP1
   16 SUM(KA)=SUM(KA)+C(KA,JA)*R(JA)
   15 R(KA)=(D(KA)-SUM(KA))/C(KA,KA)
   17 WRITE(12,58)
      DO 19 I=1,NT
      IM1=I-1
C  19 WRITE 54,IM1,R(I)
   19 WRITE(12,54)IM1,R(I)
      CALL SPOT(C,CK,OPTS(4))
C     CHECK  FOR ERROR
```

Figure 5. (Continued).

```
      WRITE(12,56)
      DO 2Ø I=1,NT
      E(I)=0
      DO 21 J=1,NT
   21 E(I)=E(I)+ C(I,J)*R(J)
      E(I)=E(I)-D(I)
   2Ø WRITE(12,57)I,E(I)
      IF(KPRT)112,111,112
  112 WRITE(12,5Ø4)
  111 SD2=Ø
      SDEV=Ø
      CHI2 = Ø.
      IF(NDEV)1Ø1,1111,1Ø1
      CALL OPEN(2,"$TTI1",Ø,IER,1)
  1Ø1 CONTINUE
  1Ø4 CONTINUE
C
C****
C
      IF(GO)1Ø6,1Ø5,1Ø5
  1Ø5 CONTINUE
C****
      YP=R(1)
      DO 1Ø3 I=2,NKP1
  1Ø3 YP=YP+R(I)*X(I-1)
      EI = YP
      YI = Y
      CHI2 = CHI2 + (YI - EI)**2 / EI
      DEV = ABS ((Y-YP)/Y)
      SDEV=SDEV+DEV
      ADEV=SDEV/C(1,1)
      SD2=SD2+(Y-YP)**2
      IF(KPRT)1Ø7,1Ø8,1Ø7
  1Ø7 WRITE(12,5Ø2)Y,YP,DEV,(X(I),I=1,NK)
  1Ø8 CONTINUE
      GO TO 1Ø4
  1Ø6 STDEV=SQRT (SD2/C(1,1))
      AVGD V=SDEV/C(1,1)*1ØØ.Ø
      WRITE(12,5Ø5)STDEV
      WRITE(12,5Ø6)AVGD V
      WRITE(12,69) CHI2
   69 FORMAT(43X,13HCHI SQUARE = ,E14.5)
      GO TO 1111
   77 STOP
      END
```

Figure 5. (Continued).

```
      SUBROUTINE PUNT(C,CK,Ø(5))
      DIMENSION C(64,64),CK(64,64),O(5)
      SUMC=Ø
      SUMCK=Ø
      DO 1 I=1,64
      DO 1 J=1,64
      SUMC = SUMC+C(I,J)
    1 SUMCK=SUMCK+CK(I,J)
      R=SUMCK/SUMC
      E=Ø
      DO 2 I=1,64
      DO 2 J=1,64
      C(I,J)=C(I,J)*R
    2 E=E+ABS(C(I,J)-CK(I,J))/CK(I,J)
      IF(E.GT.B)GO TO 88
      GO TO 99
   88 PRINT (12.5Ø)
   5Ø FORMAT(1H1,12HDATA INVALID)
      STOP
   99 RETURN
      END


      SUBROUTINE SCALE(C,CK,Ø)
      RMAX=Ø
      DO 1 J=1,64
      DO 1 I=1,64
      IF(C(I,J),GT,RMAX)RMAX=C(I,J)
    1 CONTINUE
      DO 2 J=1,64
      DO 2 I=1,64
    2 C(I,J)=C(I,J):1ØØ./RMAX
      CALL LEVEL(C,O)
      RETURN
      END


      SUBROUTINE LEVEL(C,O)
      DIMENSION C(64,64),O(15)
      RL=O(6)
      RL=1Ø
      DO 1 J=1,64
      DO 1 I=1,64
      IF (C(I,J).LT.RL) GO TO 2
    2 C(I,J)=Ø
    1 CONTINUE
      RETURN
      END
```

Figure 5. (Concluded).

Sync	Y	X	IR
Ø	Ø	21	12
Ø	21	13	33
Ø	21	13	34
Ø	21	14	38
Ø	21	14	38
Ø	21	14	34
Ø	21	15	33
Ø	21	15	31
Ø	21	15	32
Ø	21	16	34
Ø	21	16	56
Ø	21	16	57
Ø	21	47	Ø
Ø	21	34	Ø
Ø	21	18	3Ø
Ø	21	18	29
Ø	21	31	Ø
Ø	21	3Ø	Ø
Ø	21	2Ø	29
Ø	21	2Ø	29
Ø	21	2Ø	3Ø
Ø	21	21	3Ø
Ø	21	21	31
Ø	21	21	31

Figure 6. Listing of word format (a single line scan).

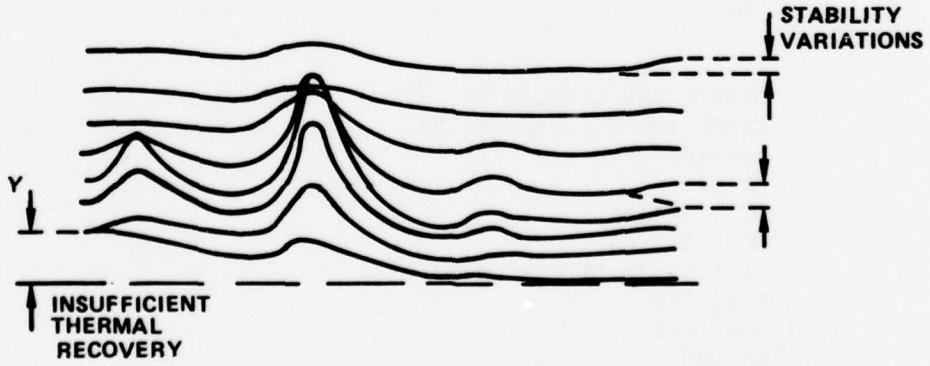


Figure 7. Analog trace of the LEECO Corporation's LCP200T sensor showing instability and poor thermal recovery.

$$\sigma_T^2 = \sigma_{R_1}^2 + \sigma_{R_2}^2 + \sigma_E^2 + \sigma_D^2$$

where σ_{R_1}* = Standard deviation of resistance

σ_{R_2} = Standard deviation of resistance

σ_E = Standard deviation of resistance due to system such as quantizing errors, etc.

σ_D = Standard deviation induced by implanting normal data upon data dropout.

*σ_{R_1} and σ_{R_2} are the left and right half of the skewed distribution of resistance effect and exist in three pairs for 5, 10, and 20% tolerances. σ_D is computed during each test as it is affected by number of data dropouts and degree of normalization needed of the test matrix.

D. Operation of System

Figure 8 is a block diagram of the system and shows information flow and processing within the test station.

Printed circuit boards were prepared for testing in pairs — one of each pair being a known acceptable board, and the second of each pair having known faults. Test boards were designed to represent typical faults including out-of-tolerance components, high-resistance solder joints, incorrect components, and missing components.

A known to be acceptable board was inserted into the scanner and allowed to reach thermal equilibrium, as established by monitoring a thermistor placed on one of the slower time constant components. After reaching thermal equilibrium, the computer was alerted by the operator via the data link. Upon receipt of the alert, the computer responded with a ready or busy signal. When the operator received a ready signal, the board identification number was entered and the computer responded with an acknowledgement. The scan is then activated which results in a thermal map of the known acceptable board being stored in the computer. Upon the proper signal by the operator, the computer accepted the thermal map as being either a new map or an update of an older map. The known acceptable board is then removed from the scanner. The board with the known fault is then placed in the scanner and its thermal map is similarly stored in the computer where the two maps are compared and the results are displayed on a printer.

The UART circuit permits the use of an interactive link which allows the operator to receive fault readouts directly from the processor.

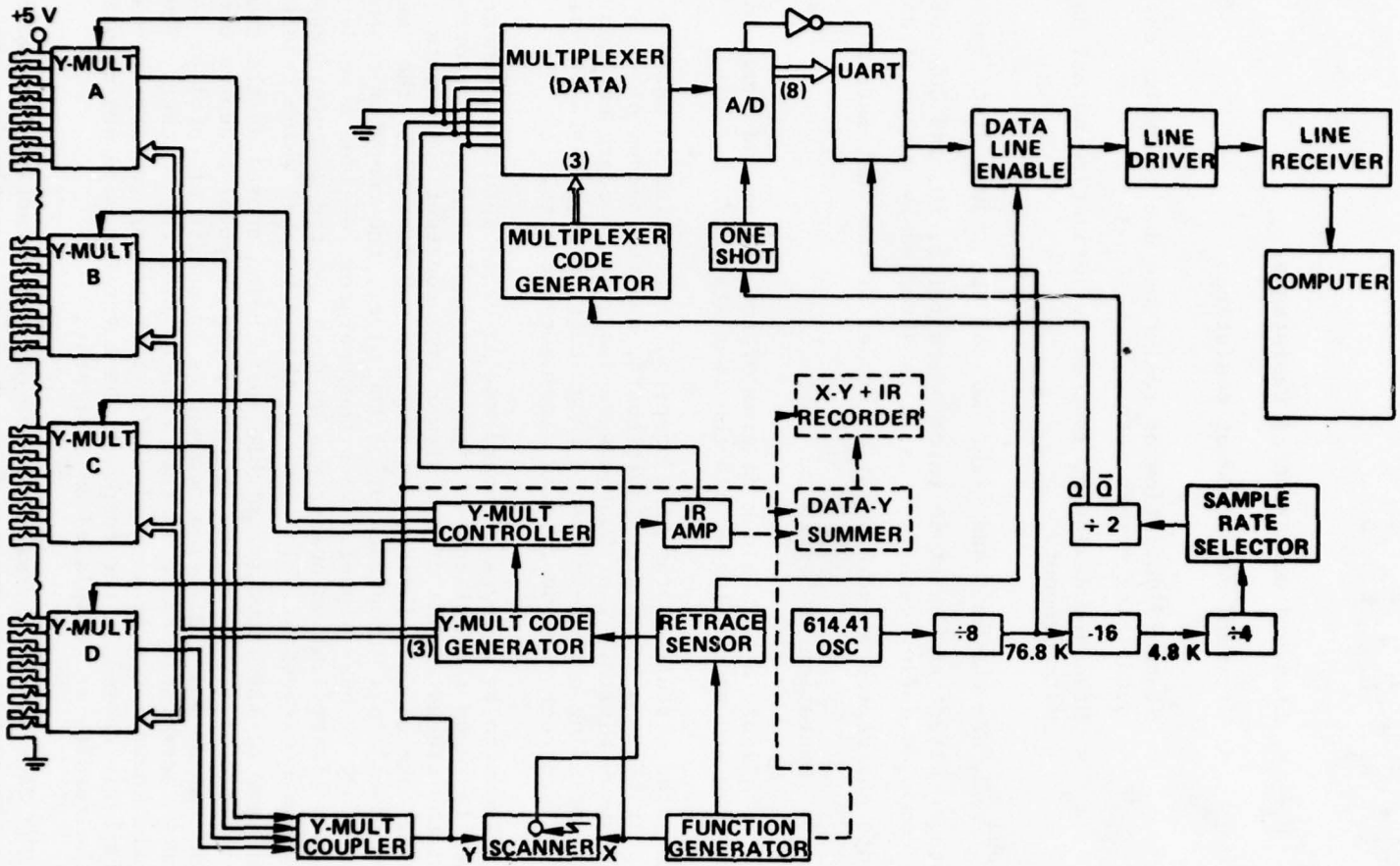


Figure 8. Data acquisition system.

III. RESULTS

The factors that adversely affect measurements are equipment drift, sensivity, board radiation, and ambient temperature change. Power supply voltages are regulated to 1%. The drift is corrected by normalizing to a standard prior to each run. Normalization should be done frequently, although the software will alert the operator if drift becomes excessive. Sensitivity is the prime parameter which enables the system to be most effective.

A. LEECO LCP200T

The baseline stability and sensitivity was measured for the LEECO LCP200T sensor. These measurements are as shown in Figure 9. Wide variations (as much as 50%) were noted in the sensitivity tests; however, the effect of power level is clearly evident.

A preamplifier was designed and built for the LEECO to obtain sufficient voltage output to interface with the data system. It was found that the preamplifier/sensor combination, with a gain of 100, would produce satisfactory results only on boards containing components stressed at or near maximum levels, as shown in Figure 9. To measure lower temperatures generated when the components were dissipating less than maximum power, amplifier gains had to be set so high that the circuits became unstable.

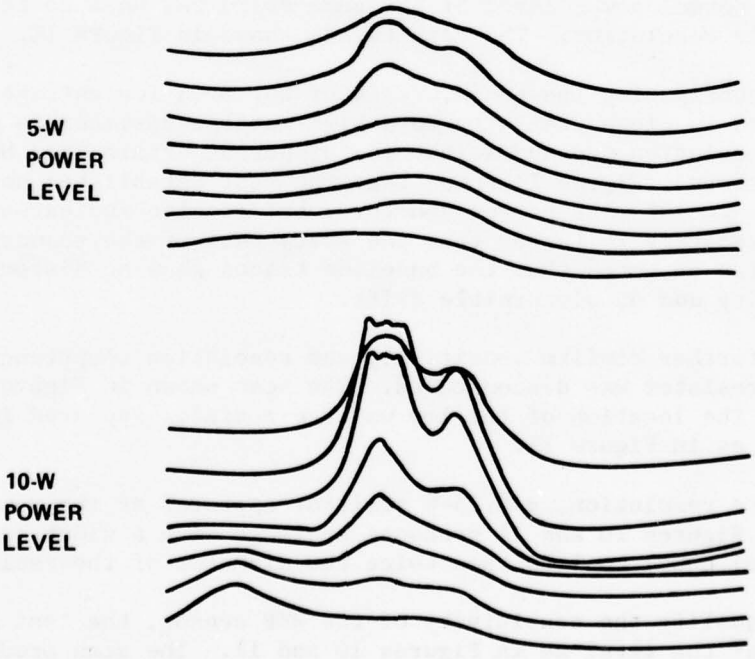


Figure 9. Readings taken from same test circuit at two different power levels.

The instability was manifested in two ways (Figure 7). Thermal drift is shown by the vertical displacement of the trace lines during times when no thermal energy sources were being scanned. A second effect of instability is shown at the left of the figure. Insufficient thermal recovery is indicated by a general escalation along the vertical axis. Attempts to alleviate the thermal recovery problem by reducing the scan speed had the effect of worsening the thermal drift problems.

B. Laser Precision Radiometer RK3440

This sensor system uses the RK3491 sensor head which demonstrated greater sensitivity and less drift than the LCP200T. The normal field-of-view of the RK3440 is 18 deg, which provided 1°C sensitivity. The wide 18-deg view angle caused a problem in supplying sufficient resolution for small components. This drawback can be resolved by two methods: (a) by software augmentation and (b) by reducing the field-of-view. The approach chosen was to narrow the aperture to 4 mm which reduced the overall sensitivity to 3°C. The reduced sensitivity remains sufficient to detect typical abnormalities.

A test board configured to verify the adequacy of the RK3440 with the narrower aperture. The board was first powered at 0.25-W level to check for sensitivity sufficiency. The 0.25-W component produced a detected signal above the energy threshhold as shown in Figure 10.

The normal power level of the same board was used to test for acceptable resolution. The results are shown in Figure 11.

In configuring the board, resistor No. 3 (a low wattage resistor) was placed in close proximity to a high wattage resistor to determine if the resolution was sufficient for proper discrimination between the two resistors. Figure 11 shows that the test established not only the basic resolution with narrow aperture, but it also indicates that the thermal recovery is faster than the sweep rate of the scanner. It should also be noted that the baseline traces show no discernible instability and no discernible drift.

To further confirm sensitivity and resolution competency, the high wattage resistor was disconnected. The scan shown in Figure 12 is the result. The location of the low wattage resistor appeared in the same location as in Figure 11.

As to resolution, a 0.25-W resistor operated at the power levels shown in Figures 10 and 11 produces an image with a width (at half amplitude) equal to less than twice the diameter of the resistor body.

To qualify the sensitivity of the RKP sensor, the test board was powered at the level as in Figures 10 and 11. The scan produced a peak amplitude of 25% of full scale when reading the 0.25-W resistor.

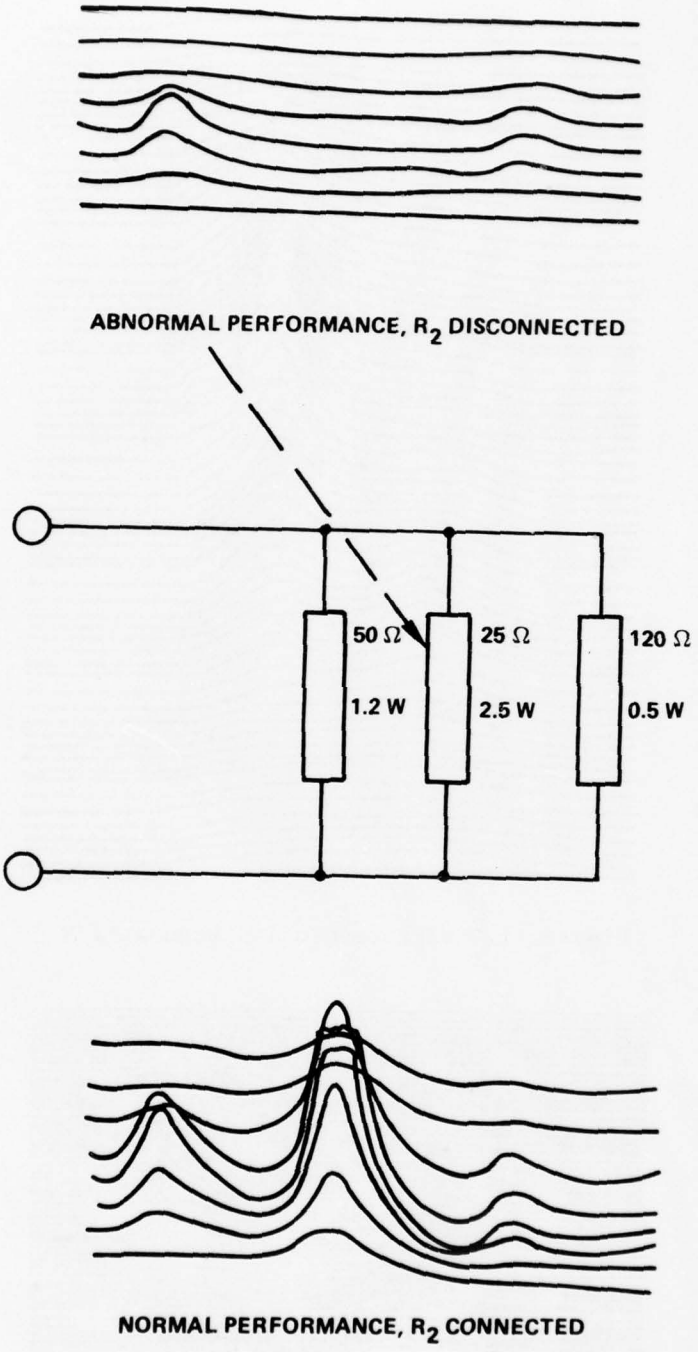


Figure 10. Scan using RK3440, showing the detection of a 0.5-W resistor in close proximity with a 2.5-W resistor.

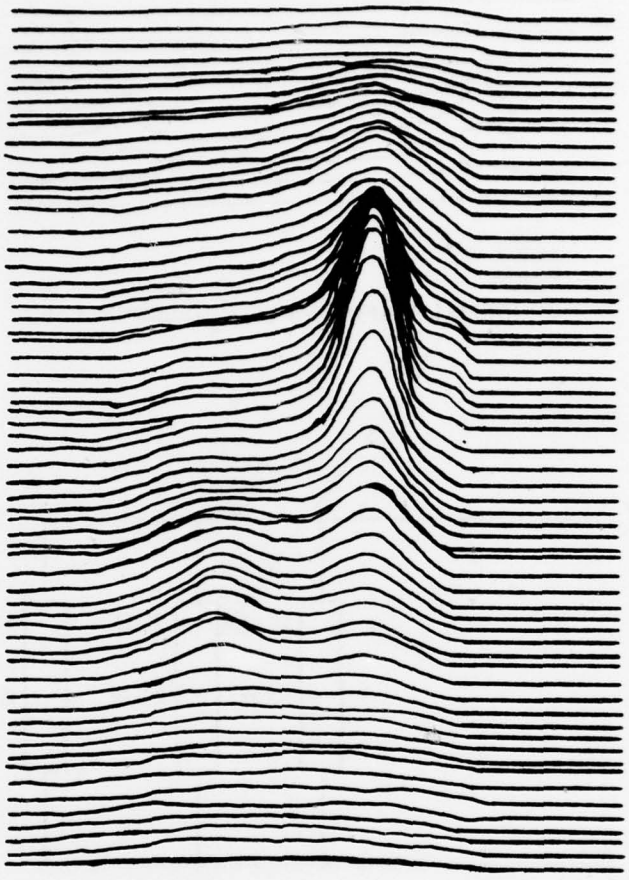


Figure 11. High resolution scan at 1 W.

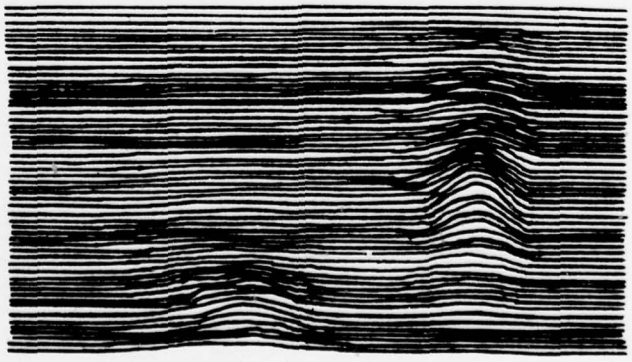


Figure 12. Resolution scan when the high wattage resistor (R_2) is disconnected.

A preliminary evaluation of the RKP-3491 Laser Precision Radiometer indicates greater sensitivity and less drift. The view angle was restricted to a 4-mm opening. This reduced sensitivity but improved resolution. The last phase of the feasibility report studied these tradeoffs and determined an optimum for each type of circuit.

The radiometer is able to pick up 0.1 W from a 0.25-W resistor. The ability to sense and resolve component radiation is illustrated by Figures 10, 11, and 12. This is the result of scanning of the card and components on Figure 2.

An expanded view of the digitized map of a single component is shown in Figure 13 for the RK3440 and the data acquisition system described. The particular component shown is a 4-W resistor operating at one-half rated level. The figure illustrates a measure of the resolution selected for use in testing discrete component printed circuits.

The detailed schematics of the data acquisition system shown in Figure 8 are displayed in the Appendix. The mechanical limit switches used early in the program have been replaced with peak detection circuitry which has built-in flexibility that accommodates different size printed circuit cards.

IV. CONCLUSIONS

A major objective of this effort was to establish the feasibility of using a noncryogenic or gas-cooled sensor which is compatible with an industrial environment. The RKP3491 has shown this capability. It has also been shown that it can be successfully used and controlled by industrial production personnel. The overall system lends itself well to multiple test stations, all operating on one central processor.

An area needing improvement is the basic frequency response of the sensor. The RKP is much faster than the LCP200T, but it is still the rate-limiting element in the system. A ten-fold increase in speed is needed to challenge microprocessor speed in a five station geometry.

The study has established the fact that the sensor is sufficiently sensitive to allow use of an aperture to refine the resolution. A more efficient approach would be to focus the view angle. However, the lack of collimation produced by focusing makes the distance from the scanned board to be critical. This critical distance can be controlled and is necessary for microspot surveys of hybrid microcircuits and integrated microcircuits.

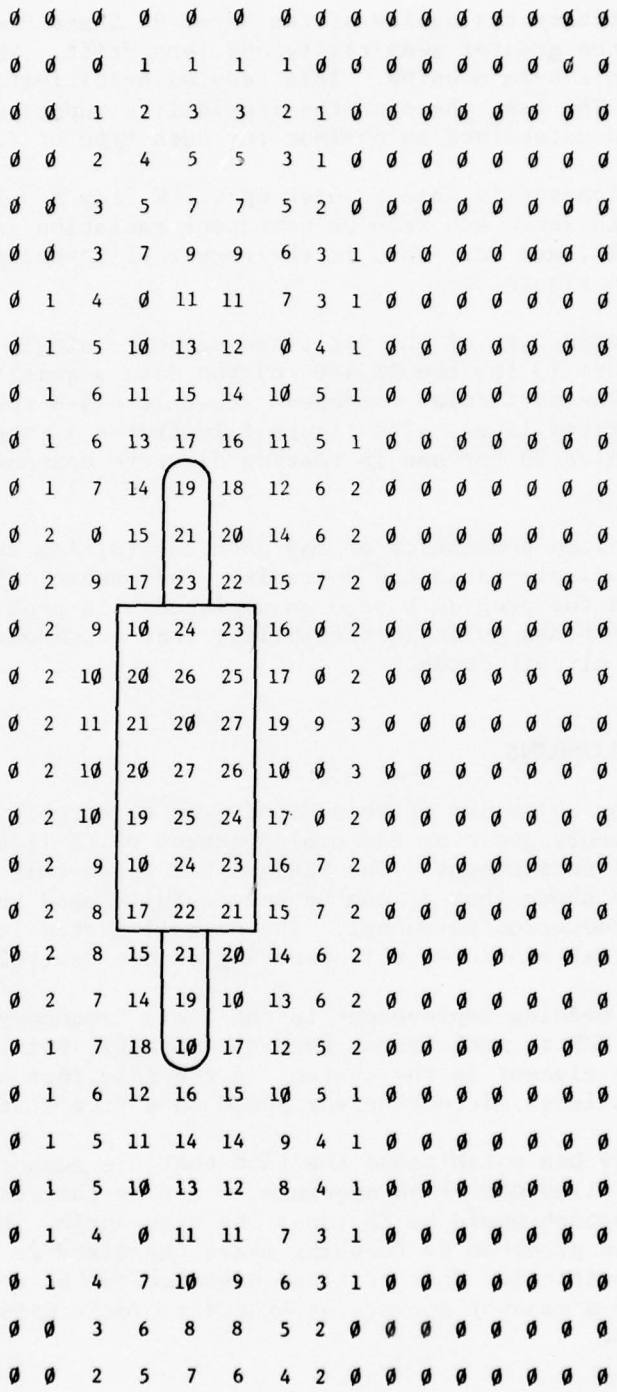


Figure 13. Expanded view of the digitized map of a single component.

A suggested following program should include an adaptive processor development in which the algorithms are matured through data collection and the development of a results-oriented data bank. Thus, a means would be provided for the optimization of the number of test stations per processor. In addition, the level of testing per card type could be defined in terms of cost effectiveness. Figure 14 depicts a logical sequence for implementing the recommended adaptive process.

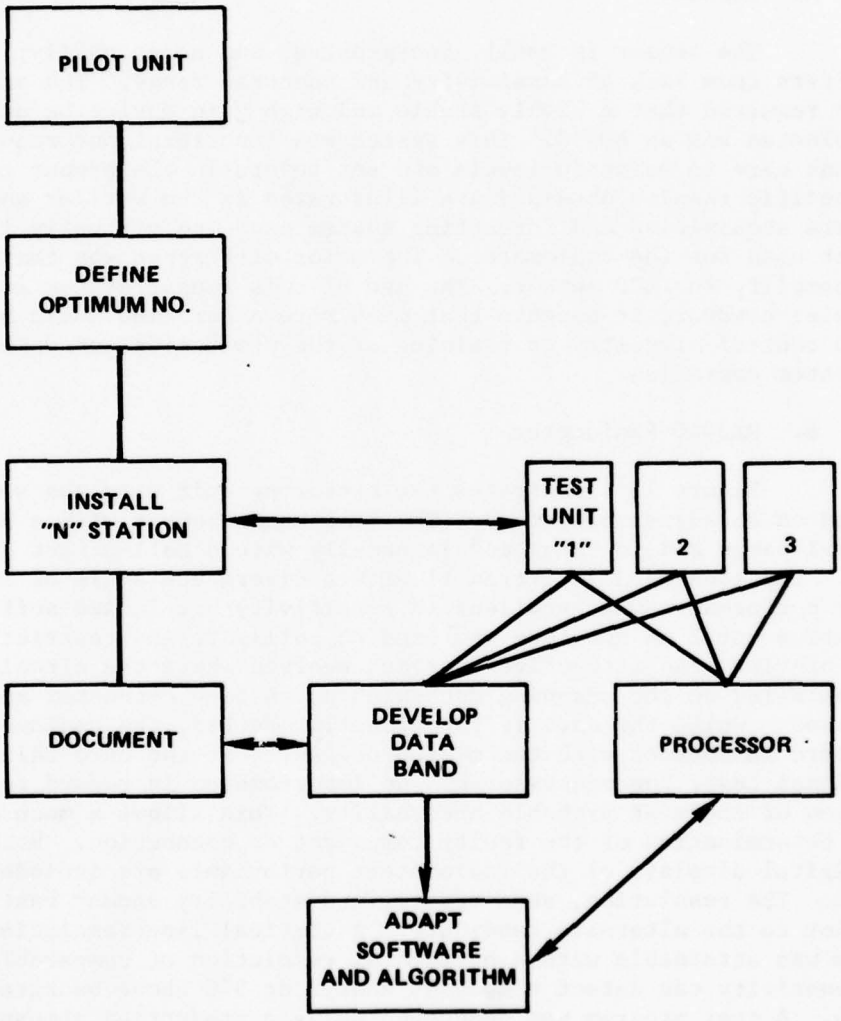


Figure 14. Adaptive development sequence.

V. SUMMARY

Both sensor systems proved to be feasible in analysis of printed circuit cards under functional operational testing. The two sensors were the LCP200T, a small TO-5 size sensor head with a germanium lens, and a Laser Precision RK3440 Radiometer. Several advantages and disadvantages accrue to each and are summarized in the following paragraphs.

A. LCP200T

The sensor is small, inexpensive, and scans easily; however, it suffers from lack of sensitivity and spectral range. The preamplification required that a highly stable and high gain device be used. The one selected was an AD510. This system was functional but required constant care to maintain levels and set points in the proper condition. The specific results obtained are illustrated in the earlier sections. The data acquisition and formatting system used was virtually identical to that used for the radiometer. The major difference was that required to preamplify the LCP sensor. The use of this sensor/system is totally feasible; however, it appears that much more automation would be required in the control circuitry or training of the production personnel in the system operation.

B. RK3440 Radiometer

Figure 15 illustrates the prototype unit with the sensor head mounted on an adjustable stand. The head has a sensor with a board spectral range and is "chopped" internally with a Hall-effect driven motor. The lens used is Irtran II with a divergence angle of 18 deg. Sensor performance was excellent in sensitivity but lacked sufficient resolution until an aperture was used to collimate and restrict the field-of-view. An attractive approach evolved where the circuit card was installed on the scanning mechanism on an edge connector and then energized. While the card is functionally checked, the radiometer scans the board in consort with the microprocessor. If the card fails the functional test, the processor can be interrogated in regard to the location of the most probable abnormality. This allows a much more rapid determination of the faulty component or connection. Both analog and digital displays of the radiometers performance are included in the report. The resolution, sensitivity, and stability appear vastly superior to the alternate candidate. A vertical line resolution of 0.8 mm was attainable with a horizontal resolution of comparable size. The senstivity can detect component heat 2 or 3°C above background levels. A test program was conducted using a production atmosphere and production personnel and results indicated over 90% confidence levels in locating the source of faults.

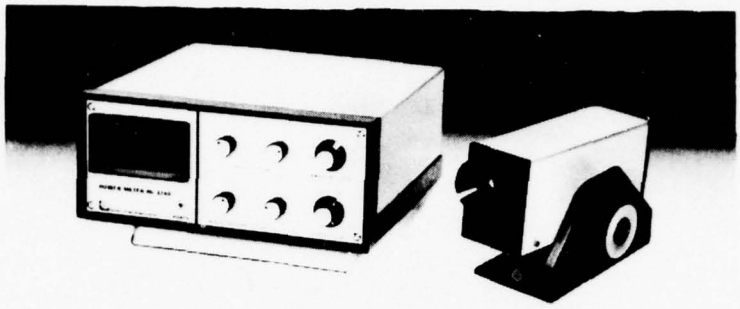
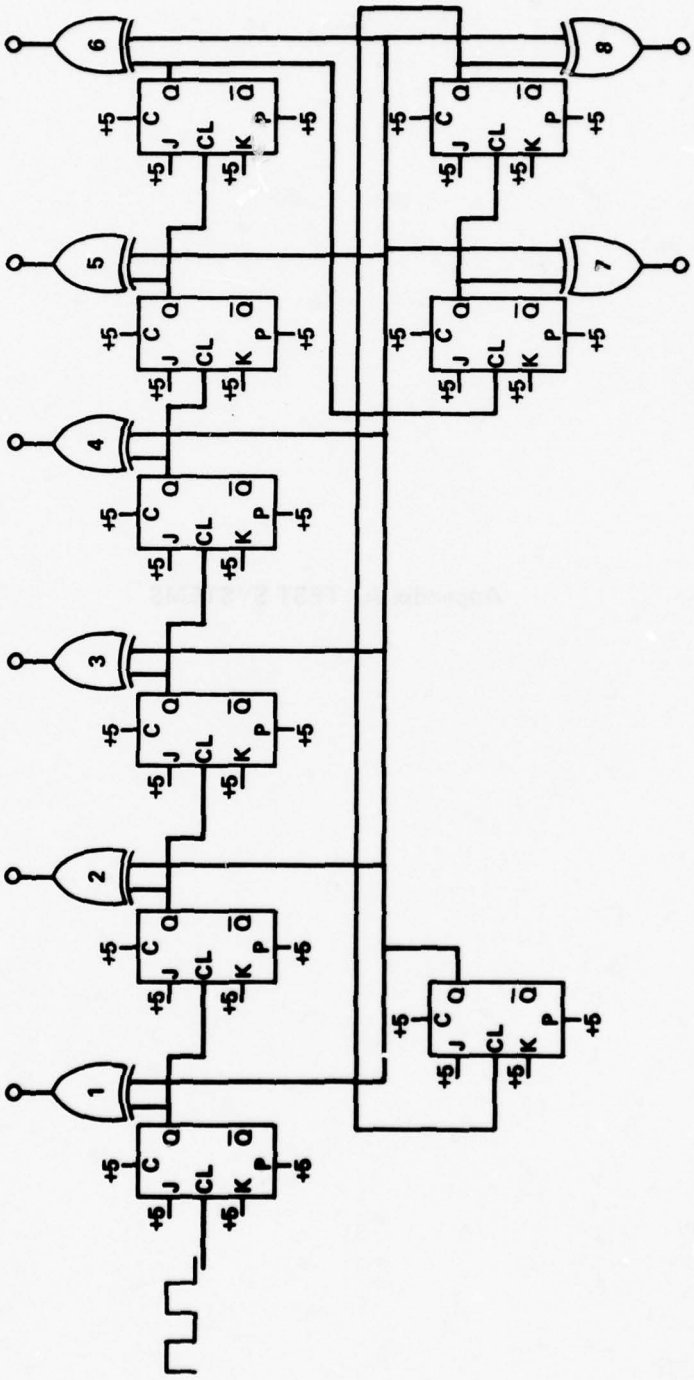


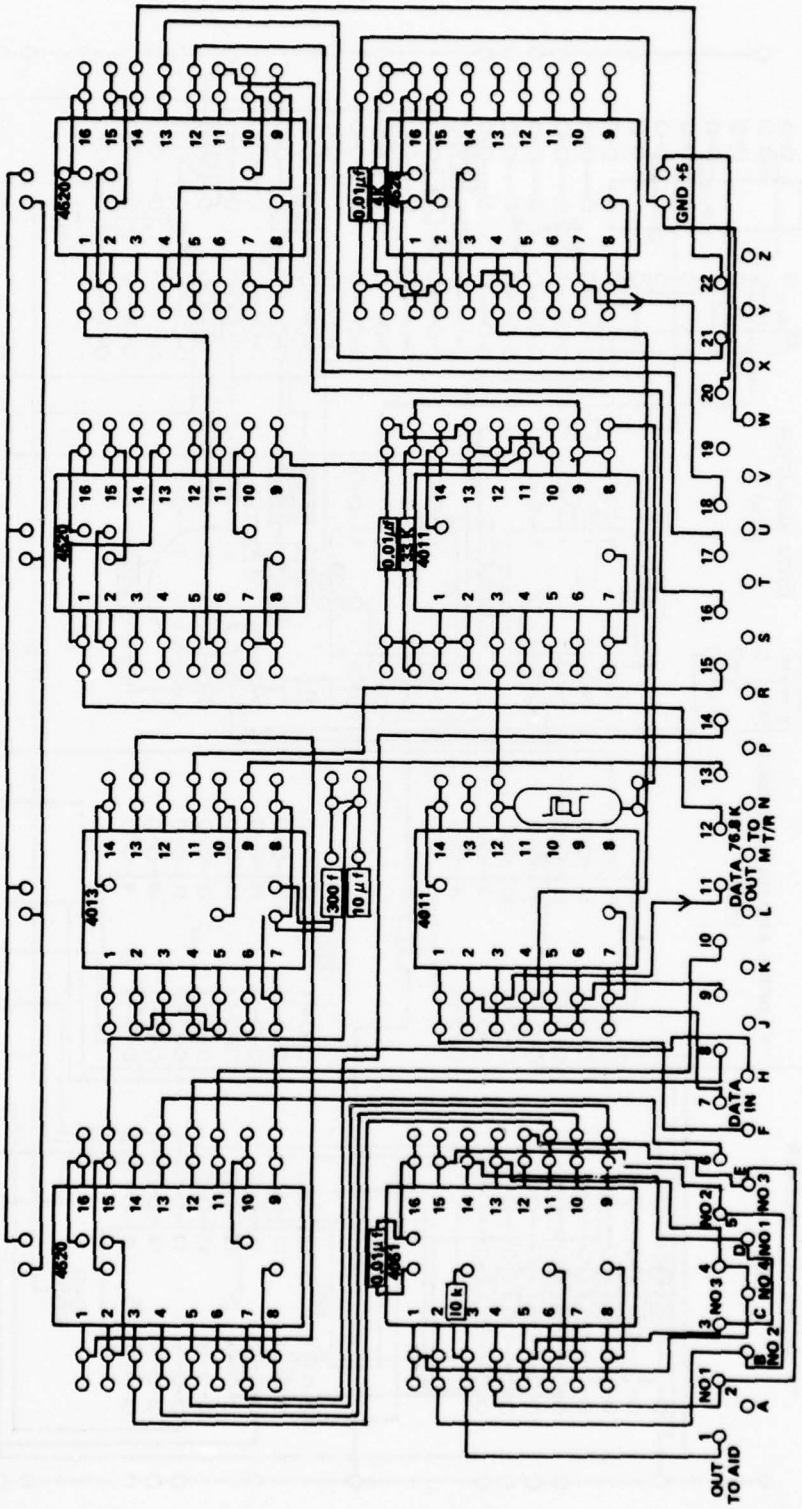
Figure 15. RK3440 radiometer prototype unit.

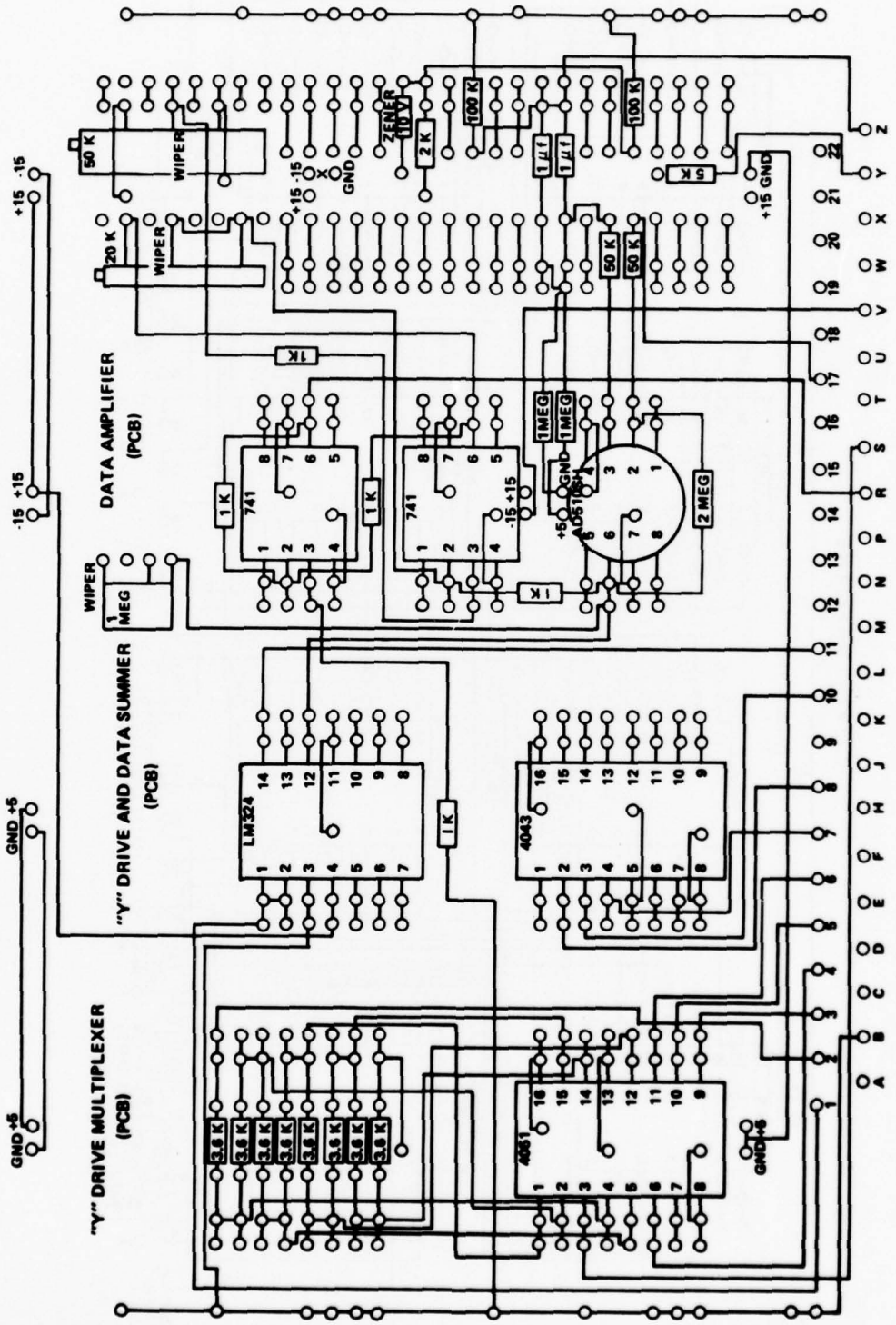
Optimization of the algorithms involved and included comprehension of all parameters that affect producibility in a production environment. The relative merit of the system depends upon the ability of the system to lower the cost of production of printed circuit assemblies. The use of IR scanning should not materially prolong the normal functional testing and perhaps should only be used when a functional fault is detected in the acceptance test of the unit. This is the most useful application of the scanner system as it locates the thermal abnormalities as they exist. This allows a more cost-effective approach to repair of printed circuit assemblies. The algorithms "decide" if a fault exists when used in the "automated" mode and minimizes false alarms. When used in the interrogate mode, the algorithms will predict the most probable location of an abnormal condition if it is reflected by an unusual thermal condition. The performance of the system has been evaluated on several types of printed circuit cards and when using the RK3440 sensor assembly has the sensitivity, resolution, and stability to vastly improve the cost effectivity of many printed circuit repair problems.

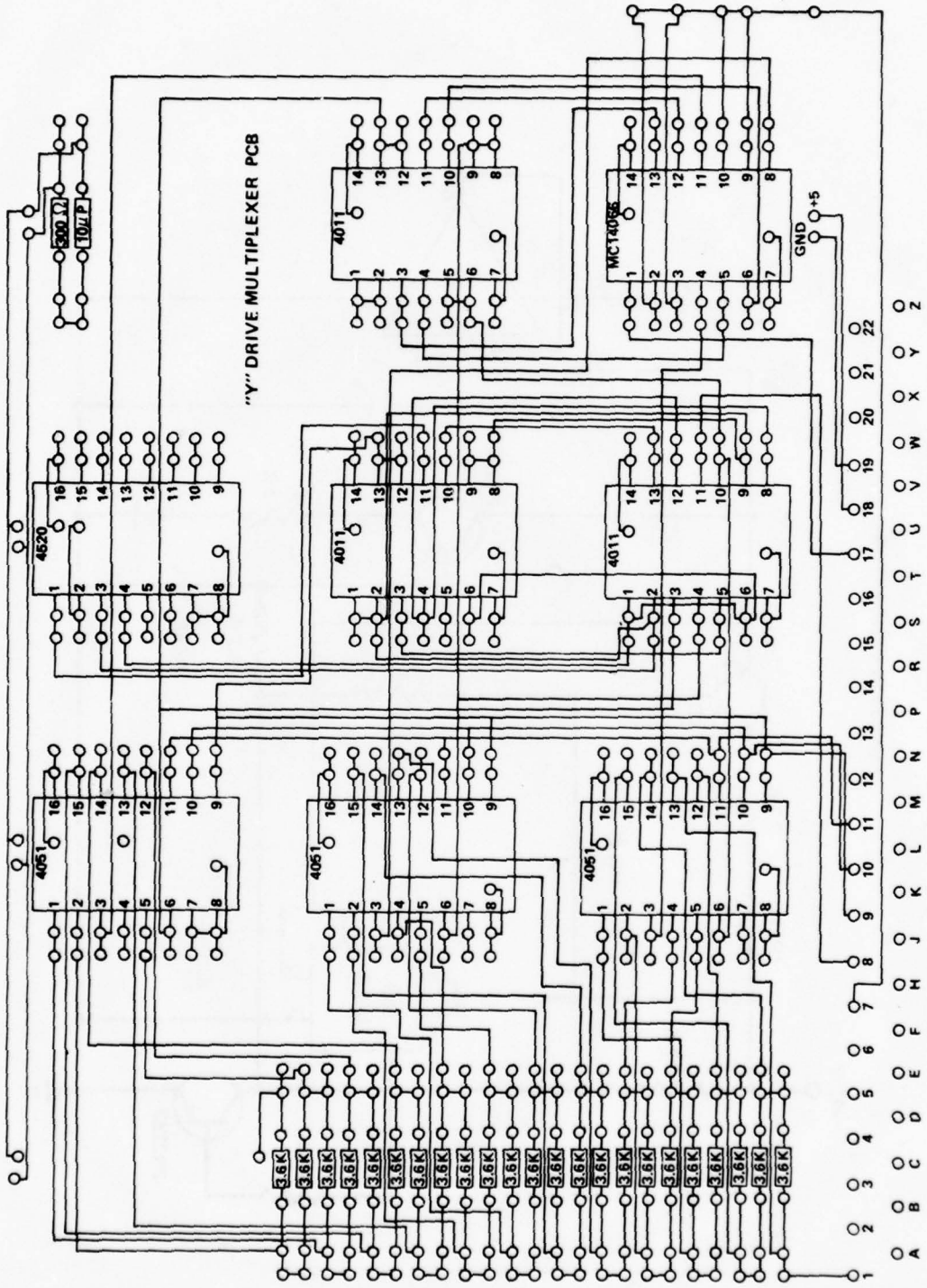
Appendix A. TEST SYSTEMS

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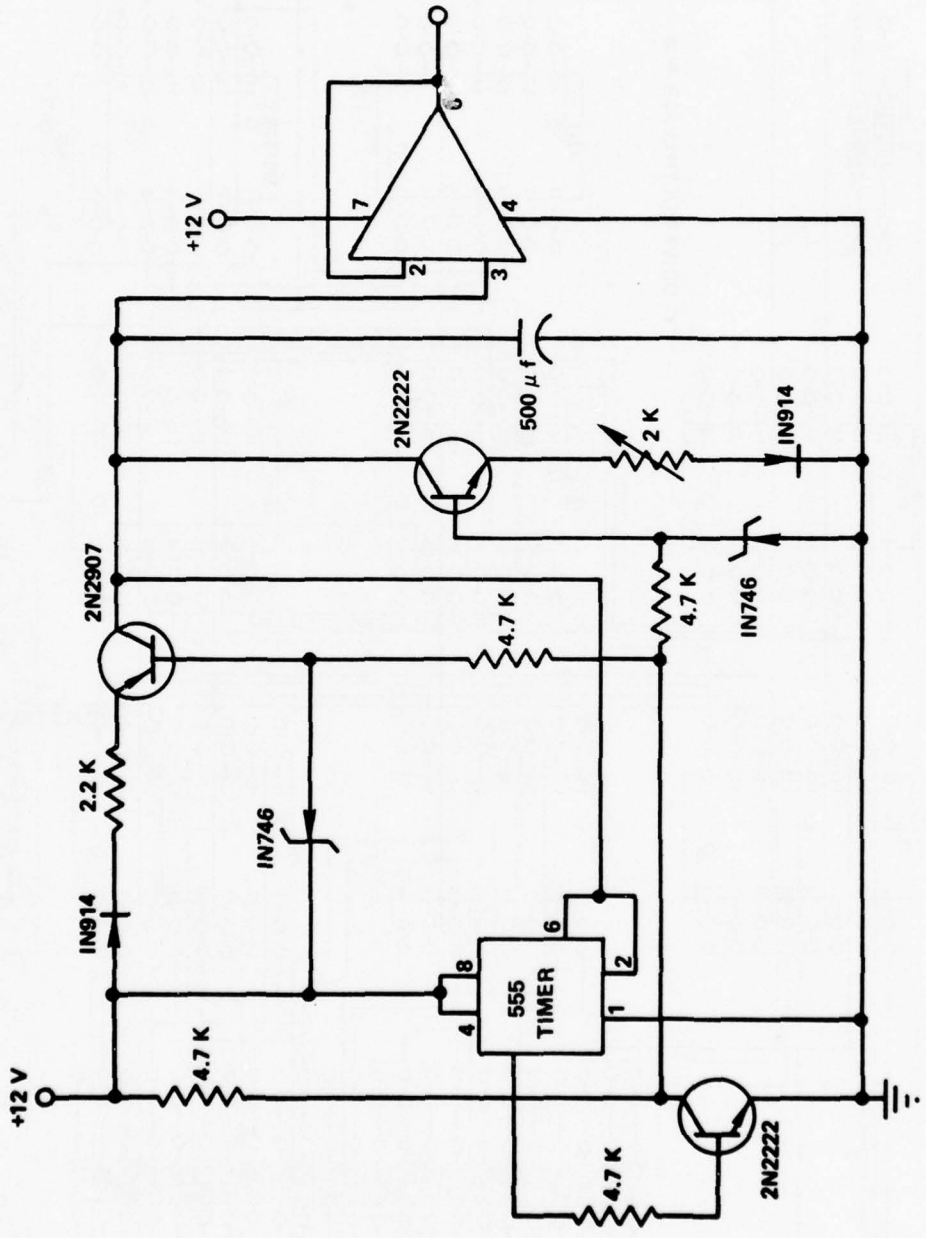

UP AND DOWN COUNTER (8 bytes)
1
2
3
4
5
6
7
8
+5
C
J
K
CL
P
Q
$\overline{Q}$

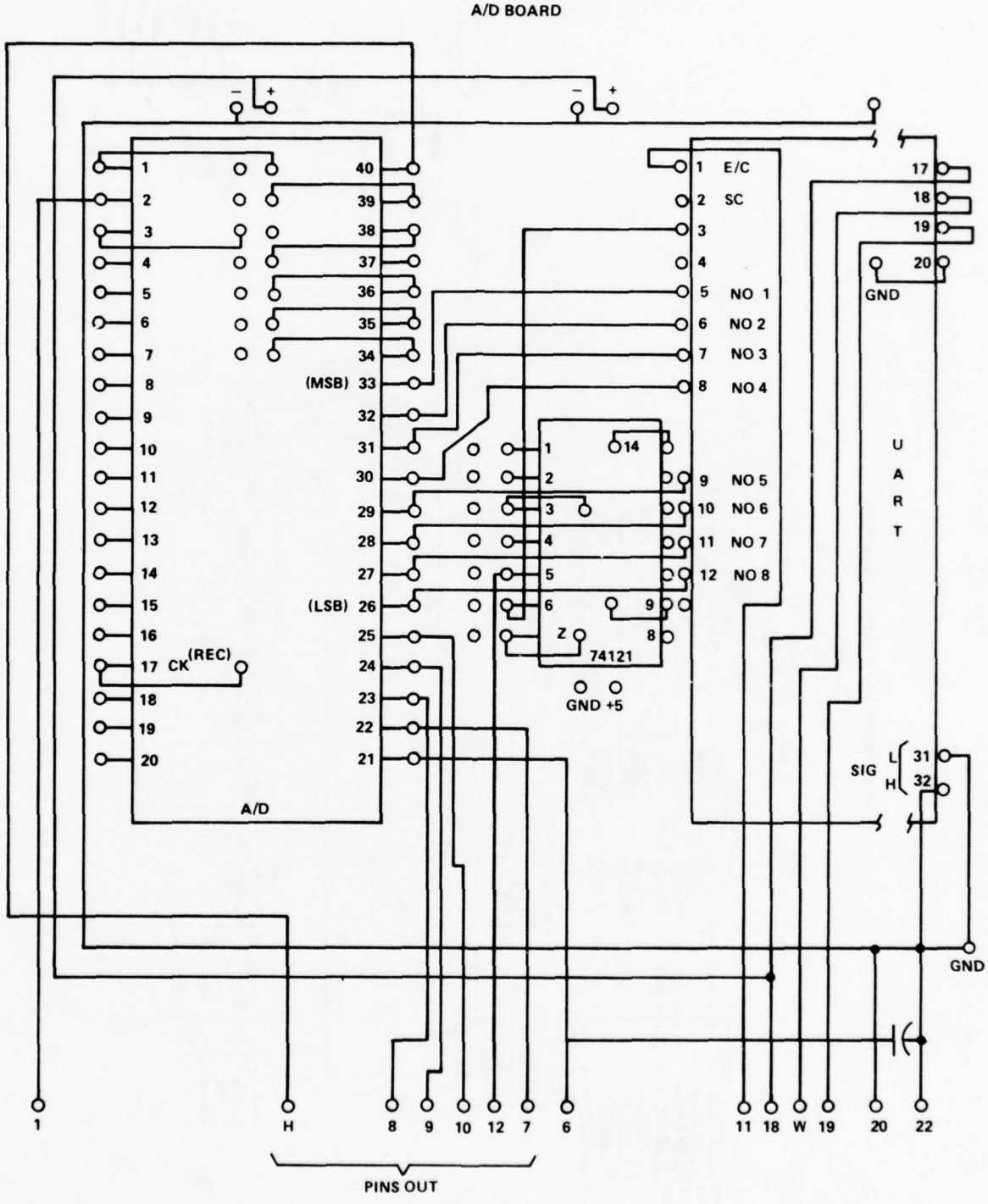

CLOCK/MULTIPLEXER PCB
4520
4520
4520
4013
4011
4011
4001
0.01μf
0.01μf
0.01μf
300 f
10 μf
10 k
GND +5
DATA OUT TO M T/R
76.8 K
DATA IN
OUT TO AID
NO 1
NO 2
NO 3
NO 4
A
B
C
D
E
F
H
J
K
L
M
N
P
R
S
T
U
V
W
X
Y
Z


"Y" DRIVE MULTIPLEXER (PCB)
"Y" DRIVE AND DATA SUMMER (PCB)
DATA AMPLIFIER (PCB)
50 K
WIPER
20 K
WIPER
1 MEG
WIPER
ZENER 10 V
2 K
100 K
100 K
1 µf
1 µf
1K
741
741
1 K
1 K
1MEG
1MEG
2 MEG
1K
LM324
1 K
4043
4051
3.6 K
3.6 K
3.6 K
3.6 K
3.6 K
3.6 K
3.6 K
50 K
50 K
+15
-15
GND
+5
A
B
C
D
E
F
H
J
K
L
M
N
P
R
S
T
U
V
W
X
Y
Z

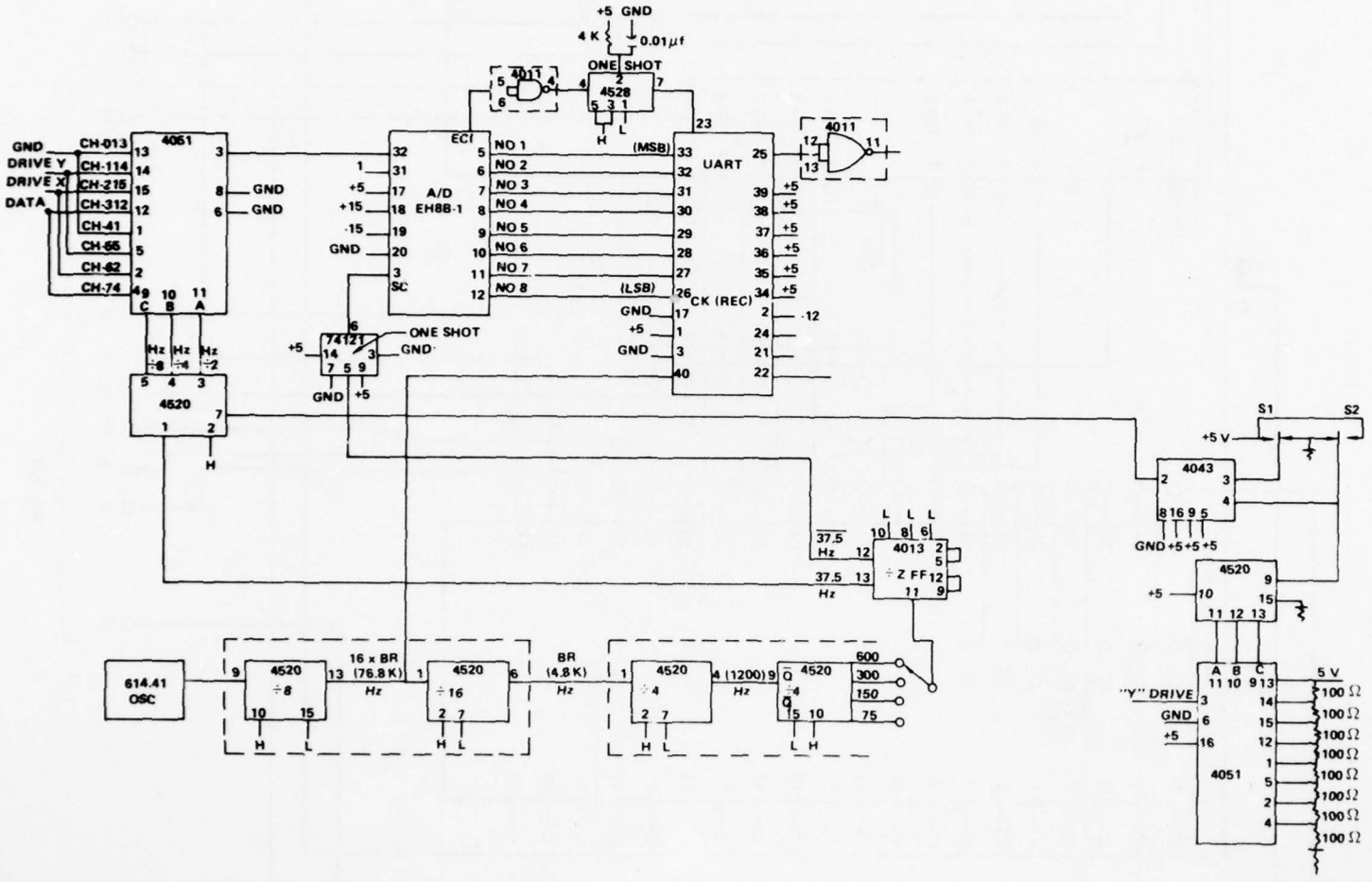

"Y" DRIVE MULTIPLEXER PCB
4520
4011
4011
4011
MC14066
4051
4051
4051
300 Ω
10μF
GND
+5
3.6K

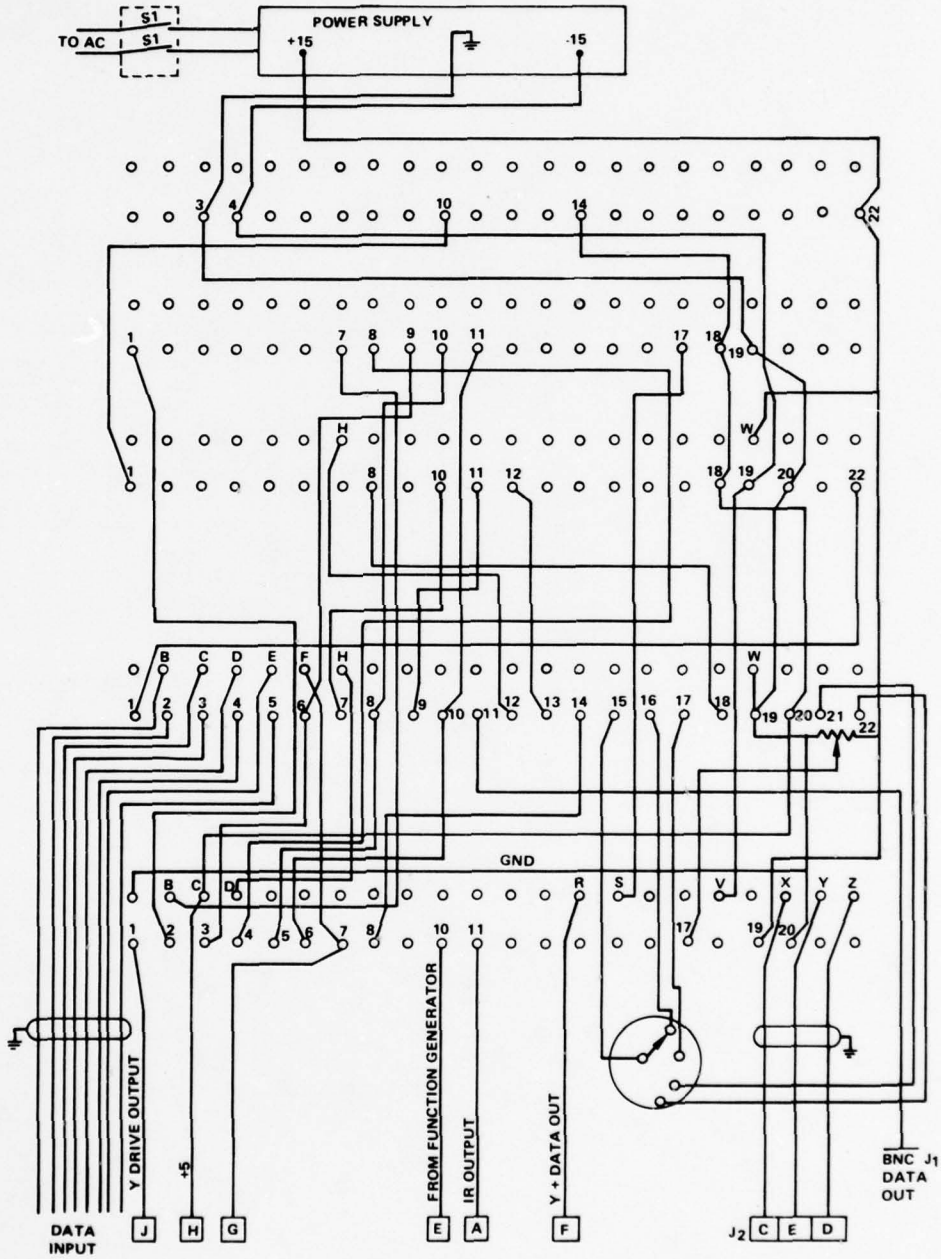
FUNCTION GENERATOR




A/D BOARD
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17 CK (REC)
18
19
20
40
39
38
37
36
35
34
(MSB) 33
32
31
30
29
28
27
(LSB) 26
25
24
23
22
21
A/D
1 E/C
2 SC
3
4
5 NO 1
6 NO 2
7 NO 3
8 NO 4
9 NO 5
10 NO 6
11 NO 7
12 NO 8
1
14
2
3
4
5
6
9
Z
8
74121
GND +5
17
18
19
20
GND
U
A
R
T
SIG
L 31
H 32
GND
1
H
8
9
10
12
7
6
11
18
W
19
20
22
PINS OUT

MULTIPIEXER, UART, AND A/D CONVERTER




S1
TO AC
S1
POWER SUPPLY
+15
-15
GND
Y DRIVE OUTPUT
+5
FROM FUNCTION GENERATOR
IR OUTPUT
Y + DATA OUT
BNC J1
DATA
OUT
DATA
INPUT
J2

Appendix B. Rk-3400 SERIES RADIOMETERS OPERATING INSTRUCTIONS

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Rk-3400 SERIES RADIOMETERS

OPERATING INSTRUCTIONS

LASER PRECISION CORPORATION
1231 Hart Street
Utica, New York 13502 U.S.A.

Telephone: (315) 797-4449

IS-344-10B
April 1977



FIGURE CAPTIONS

Standard Rk-3440

Figure 2-1: Rk-3440 Block Diagram

Figure 2-2: Timing Diagram

Figure 2-3: Power Supply Primary Connections

Figure 2-4: Rk-3440 Signal Processing Circuitry and Switch Assembly

Figure 2-5: Wiring Diagram

Figure 2-6: RkP-341,345,349 Preamplifier

Figure 2-7: Window Transmission

Figure 2-8: Motor Drive Circuit

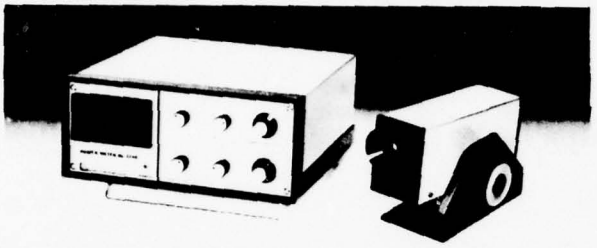
Rk-3442 Power Ratiometer

Figure 6-1: Rk-3440 Option 01

Figure 6-2: Rk-3441 Ratio Circuit

Figure 6-3: Power Supply Schematic

Rk-3400 SERIES
POWER METER/RADIOMETERS



THE STANDARD OF VERSATILITY AND PERFORMANCE FOR OPTICAL, THERMAL, AND LASER MEASUREMENT

The Rk-3400 Series has been developed to provide, in a single spectrally flat instrument, both the sensitivity required to perform low level visible and IR radiometric measurements and the ruggedness and uniformity necessary to measure the power of concentrated laser radiation. Its design is based on the most recent developments in pyroelectric detection combined with the use of phase locked electronic circuitry.

CHOICE OF RADIATION PROBES: Four interchangeable probes are available for use with Rk-3400 radiometers: The RkP-341 is intended primarily for broad-band measurement of irradiance (Watts/cm^2) or radiance (Watts/cm^2 Sr). The 1.0cm^2 RkP-345 measures either irradiance, radiance, or the total power of a collimated laser beam (up to 1000 Watts with model RkA-410 Attenuator and model CTX-430/425 chopper attenuator). The RkP-349 spot probe utilizes a small area detector and a lens to measure either low power levels or radiance from a remote target.

The unique performance of the radiation probes is made possible by the use of extremely stable pyroelectric detector elements. The response of these elements is a locked-in property of their crystal structure and will not degrade unless seriously misused. This fact, along with the use of precision electronic components and circuitry makes the Rk-3400 ideal for use as a transfer standard.

FLAT SPECTRAL RESPONSE: The extremely flat response of the RkP-341 and RkP-345 probes results from the use of both a black detector coating and a construction which redirects any radiation not initially absorbed by the coating back to the detector surface. This design has been proven experimentally to be more than 99% absorbing from 0.4μm to 3μm and 96% absorbing from 0.25μm to 16μm.

LOCK-IN ELECTRONICS: The use of optical chopping in conjunction with phase sensitive rectification yields the stability inherent in AC radiometry along with highly efficient noise rejection. Two readouts are available: The Rk-3440 standard instrument and the Rk-3441 ratiometer. Both feature a choice of three response times plus a ten turn control to cancel either hot or cold background signals. In addition, the design provides for the optional substitution of a remote chopper for the internal probe chopper. This allows discrimination of a weak localized source in the presence of a strong or varying background and is particularly useful when making ratio measurements.

CALIBRATION: The Rk-3440 is intended to function as a laboratory transfer standard. It is inherently more stable than most common optical references and thus should be calibrated only by means of an electrically calibrated pyroelectric radiometer, a black body source, or other radiation standard traceable to the National Bureau of Standards.

FEATURES

- Power measurement from 3×10^{-9} to 1000 Watts
- Light Trapping Structure for Flat response from UV to far IR
- Internal Optical Chopping and Phase Locked Circuitry
- Uniform detector areas to 1cm^2
- Measurement of power, irradiance, radiance

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RkP-341 RADIOMETRIC PROBE: The RkP-341 consists of a precisely fabricated pyroelectric sensing element, an internal optical chopper, and a feedback preamplifier designed for maximum short and long term stability. It utilizes a light trapping detector design with an active area of $0.1cm^2$ (3.57mm diameter).

RkP-345 LASER POWER PROBE: This probe is designed to measure the total power of laser beams having diameters up to 1.128cm and power levels from 2×10^{-7} to 10 Watts (100 Watts with RkA-410). In addition, its accurate $1.0cm^2$ active area allows it to be used for wide range radiometric measurements.

RkP-347 LASER SAFETY PROBE: The RkP-347 uses a fixed focus fused silica lens and a high sensitivity detector to achieve the resolution required for laser safety monitoring in the visible and near IR portions of the spectrum.

RkP-349 RADIOMETRIC SPOT PROBE: This probe uses an adjustable lens assembly to provide an angular resolution of approximately 2°. It can be used either for low level power or irradiance measurement or to measure the radiance of a remote target. Two lens materials are available: fused silica (RkP-349 V) and ZnSe (RkP-349 I).

RkW-300 SERIES WINDOWS: These windows are effective in reducing air coupled acoustic disturbances when making extremely low level measurements. Specify RkW-301 (Suprasil) or RkW-302 (Irtran II) for use with RkP-341, and RkW-351 (Suprasil) or RkW-352 (Irtran II) for use with RkP-345. A choice of one window is included with each RkP-345.

RkA-410 ATTENUATOR: This reflective attenuator extends the range of the RkP-345 probe to approximately $100W/cm^2$. The measured transmission is stamped on each attenuator.

CTX-430 AUXILIARY FIXED SPEED CHOPPER: When making low level measurements it is often convenient to utilize a chopper located near the radiation source rather than at the probe. This greatly reduces the masking effects of background radiation by insuring that only the desired signal is chopped. The CTX-430 provides for this mode of operation.

RkA-425 ATTENUATOR BLADE: *Converts* the CTX-430 chopper, to a 25x attenuator. Used in conjunction with the RkA-410, it allows measurement of powers up to 1000W.

RkG-412 FIBRE OPTIC LIGHT GUIDE: Designed for use in making visible region measurements in hard to reach locations, the RkG-412 fits directly into the accessory adaptor of the RkP-341 probe.

OPTION RF: ENHANCED FAR IR RESPONSE: Available on all three probes, this option improves the response in the 20μm to 500μm region without sacrificing performance at other wavelengths.

OPTION RB: BCD OUTPUT: Provides a rear panel interface for use with a digital printer or other data storage unit.

AVAILABLE READOUTS

Two readouts are available for use with the radiation probes: the Rk-3440 standard instrument and the Rk-3441 ratiometer. The latter is identical to the Rk-3440 except for the addition of ratioing circuitry. It can be used with one probe as a single channel instrument or combined with an Rk-3440 and a second probe to perform ratio measurements. A front panel switch on the Rk 3441 allows its operation to be switched from direct readout to "RATIO". In the latter mode, the range switches for the individual readouts can be used to provide a comparison of either similar or widely differing levels.

SPECIFICATIONS (Rk-3440 or 3441 with indicated probes)

Probe	RkP-341	RkP-345	RkP-347	RkP-349
Sensing Area (cm^2, circular)	$0.1 \pm .005$	$1.0 \pm .005$	$1.0 \pm .005$	2.7, nom.
Irradiance Resolution (w/cm^2)				
– external chopper	10^{-7}	2×10^{-7}	5×10^{-9}	10^{-9}
– internal chopper	3×10^{-7}	6×10^{-7}	5×10^{-8}	10^{-8}
Power Resolution (watts)				
– external chopper	10^{-8}	2×10^{-7}	5×10^{-9}	3×10^{-9}
– internal chopper	3×10^{-8}	6×10^{-7}	5×10^{-8}	3×10^{-8}
Maximum Irradiance (w/cm^2)	10	10	10^{-2}	10^{-2}
Spectral Flatness (%)				
– 0.4 to 2.0 μm	± ½	± ½	± 5	*(below)
– 0.25 to 16 μm	+½, -4	+½, -4	NA	*(below)
Active Area Uniformity (%)	NA	± 5	± 5	± 5
Field-of-view (nom.)	0.1 Sr	0.1 Sr	5°	2°
Probe Dimensions l x w x h (cm)	23x6.3 x8.9	24x8.9 x10.1	23x6.3 x8.9	23x6.3 x8.9
Irradiance Calibration Accuracy ($2mW/cm^2$ scale)	± 1.5% of reading		± 0.5% of full scale	
Scale Ratio Accuracy	± 1%			
Linearity	within 2% up to 1/5 maximum irradiance within 5% at maximum irradiance			
Zero Drift	$10^{-6} W/cm^2$, maximum drift within one hour, after 30 minute warmup (internal chopper)			
Time Constants	0.1, 1, and 10 seconds			
Overall Temperature Coefficient	less than 0.2%/°C			
Auxiliary Outputs	Analog, Mixer, and Optional BCD			
Readout Dimensions	28 x 28.2 x 11.9 cm			

*Spectral Response

RkP-349 V (fused silica): ± 5 % from 0.3 μm to 2 μm

RkP-349 I (ZnSe): ±10% from 0.6 μm to 14 μm

RATIOMETER SPECIFICATIONS (Rk-3441)

Ratio Range	0.000 to 1.050 times ratio of range settings
Ratio Linearity	within ±1% from 0.100 to 1.050
Stability	±2% of full scale (assuming channel A reading exceeding 20% of full scale)

NOTES:

A. Higher accuracy is attainable at specific wavelengths by means of special calibrations.

B. A recalibration service is available from Laser Precision Corp.

1. INTRODUCTION

The Rk-3440 is a wide band radiometer system designed for measurement of continuous radiation with power densities ranging from 10^{-9}W/cm^2 to 10W/cm^2. Three power probes are available, each containing an internal 30 Hz chopper, pyroelectric detector and preamplifier. Fixed and chopper attenuators are also available to extend the maximum irradiance to as much as 1000W/cm^2.

Provision is made for external chopping directly at the source. This provision eliminates errors caused by high ambient radiation levels. The Rk-3440 is directly compatible with Laser Precision's CTX-534 and CTX-430 Optical Choppers.

Seven ranges are provided with full scale power densities ranging from 20μW/cm^2 to 10W/cm^2. Three averaging times are provided with time constants of 0.1, 1 and 10 seconds.

The detectors employed have flat spectral response (±2%) in the region of 0.3 to 16 microns. Overall accuracy is ±4% of reading, ±1% of full scale with the detector fully illuminated.

2. DESCRIPTION

2.1 Readout Controls and Connections:

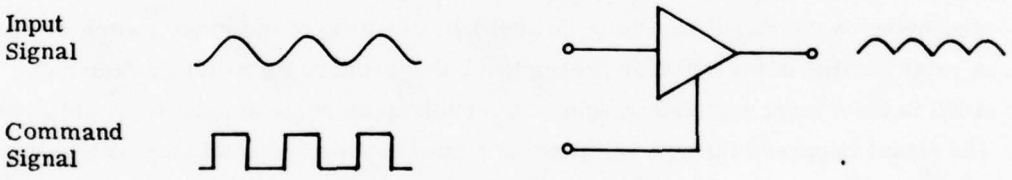
CONTROL	FUNCTION
Range Switch	Selects one of seven ranges: 20μW/cm^2, 200μW/cm^2, 2mW/cm^2, 20mW/cm^2, 200mW/cm^2, 2W/cm^2, 10W/cm^2.
Window Transmission %	Compensates for transmission losses in detector window. For example: The uncoated Irtran II window provided is 70% transmissive at 10.6 microns; thus the window transmission setting would be 70.
Phase	Allows compensation for chopper phase shift when a small diameter beam is off the detector axis. Also allows compensation for external choppers with sync pickoffs at positions different from the RkP-345 (i.e. CTX-534).
Averaging Time	Selects the amount of time the desired signal is averaged. Thus allowing a tradeoff between response speed and noise equivalent power.
Cold-Off-Hot	Allows cancellation of radiation introduced by temperature differences between the detector and the field-of-view. Hot or cold background may be compensated for.
Background Null Vernier	Adjusts the level of background radiation that is cancelled.
Chopper-Int.-Ext.	Selects the mode of chopping to be used.

CONNECTIONS PROVIDED

Direct Output	Provides a D. C. level proportional to radiation intensity
Ext. Sync.	Input for external chopper sync. signal
Mixer Out	Provides access to synchronous rectifier output
BCD Connector (Optional)	Provides BCD Output and timing signals

2.2 THEORY OF OPERATION: (Ref Figure 2-1)

The Rk-3440 is a fixed frequency lock-in amplifier and digital readout. It is calibrated in units of Watts/cm^2. A lock-in amplifier is a device that has the useful property of making a low pass filter act like a high Q bandpass filter. This filter is tuned by means of a reference signal thus avoiding the attendant drift and instability inherent in conventional high Q active filters. The heart of the lock-in amplifier is the synchronous rectifier. It is essentially an amplifier that has a gain of +N or -N depending on the state of a command signal. If the command signal is switched in synchronism with the zero crossings of the signal of interest, full wave rectification will result.



It is important to note that the operation differs from a full wave rectifier in that it is possible for negative outputs to occur. If for example we were to input random noise, the output would still be random noise and would be indistinguishable from the input.



If the inputs discussed thus far were combined, the output would be the superposition of the fully rectified signal and random noise. The average value of the signal is 63.7% of the peak value while the average value of the noise is zero. By feeding the output of the synchronous rectifier through a low pass filter the D.C. component of the signal is passed while the noise is attenuated. For a single pole low pass filter the noise equivalent bandwidth is 1/4T where T is the filter time constant.

In the Rk-3440, the signal from the probe preamplifier is attenuated by factors of 0db, 20db or 40db depending on the range switch setting. The signal is then prefiltered by an inverting 30 Hz bandpass filter with a Q of approximately 5. This serves the function of attenuating large noise peaks that might overdrive the synchronous rectifier. The filtered signal is then amplified by the gain stage located on the range switch assembly. This stage provides gains of 10 or 1 depending on the range selected. In addition, one gang of the range switch controls a relay located in the detector preamplifier that reduces its gain by a factor of 1000 in the 4 least sensitive ranges. After the appropriate amount of amplification, the signal is passed through an inverting amplifier with a gain of from one to two which varies inversely with the setting of the "Window Transmission" control. This provides gain compensation for optical losses incurred when a window is used with the probe.

The signal is A.C. coupled to voltage follower U5 which provides the low output impedance necessary to drive the synchronous rectifier U6. The rectified signal from U6 is then filtered by the low pass filter U7, and presented to the digital panel meter for display (ref. Figure 2-4).

The digital portion of the instrument provides timing and control signals to the synchronous rectifier, digital panel meter and the background cancelling circuits present in the various probes. The reference signal from the probe (or in the externally chopped mode, the reference signal from the external chopper) is supplied to Q1 for purposes of amplification and wave shaping. U1A is a Schmitt trigger gate that converts the relatively slowly varying reference signal to a TTL compatible signal with fast rise and fall times. Q 2 in conjunction with C1 and R5 differentiates the reference signal and causes Q3 and Q4 to alternately trigger the delay one shot U2A. The delay one shot permits compensation for phase errors due to small diameter beams that may not be aligned with the detector axis. In addition, in the external chopping mode, it allows the use of external choppers whose phase relationship between the sync output and the chopped radiation may differ from that of the internal chopper.

After a delay determined by the setting of the front panel Phase control, the output of the delay one shot toggles flip flop U3. The outputs of U3 serve to drive the level shifters consisting of Q5 and Q6. These in turn control the state of the synchronous rectifier. U1B serves to lock the flip flop into synchronism with the input reference signal. Trigger one shot, U2B, triggers the panel meter at the proper time so that the reading will be the same at all settings of the averaging time switch.

Synchronous Rectifier - Q7, Q8 and U6 comprise the synchronous rectifier. With Q7 and Q8 cutoff, amplifier U6 is operating in the non-inverting mode with a voltage gain of:

$$A_V = \frac{R27 + R26}{R26}$$

When Q7 and Q8 are turned on, the non-inverting input of U6 is a ground potential. (Q7 and R22 form a voltage divider that drops the voltage at Q7's emitter to a few tens of millivolts. Q8 and R24 further divide this offset voltage to essentially ground potential.) This places amplifier U6 into an inverting configuration with voltage

gain of:

$$A_V = \frac{-R27}{R25}$$

Equating the gain magnitudes we see that the gains will be equal and opposite for the two modes if:

$$R25 = \frac{R27 \times R26}{R27 + R26}$$

Low Pass Filter - Amplifier U7 is an inverting single pole low pass filter. R35 in conjunction with C9, C10, or C11 forms a feedback network with break frequencies of 1.6Hz, 0.16Hz and 0.016Hz respectively. Zero adjustment, R29 controls the amount of current injected into the summing junction of U7 so that the sum of the offset voltages in U6 and U7 may be nulled to zero.

30Hz Bandpass Filter - U4 is a multiple feedback bandpass filter. It has a voltage gain of -16 at its center frequency (30Hz). The filter may be tuned over a small range by adjustment of R20. The Q of this filter is approximately 5.

Range Amplifier - Operational amplifier U1 located on the range switch is a non-inverting amplifier with fixed gain steps of 10 or 1. Amplifier U2 has a variable gain that is set by the placement of R404, the window transmission control, and R9 which adjusts the entire system gain.

2.3 Available Probes (ref. Figure 2-6):

RkP-345

The RkP-345 detector assembly is designed for measurement of power or irradiance. It contains a 1 cm^2 pyroelectric detector, preamplifier, background cancellation electronics, a Hall-effect motor, chopper and associated speed control and commutating electronics.

Amplifier U1 integrates the minute charge displacements from the detector. It has two gain settings that are selected by relay K1. The ratio of the gain settings is adjusted to precisely 1000:1 by trimmer R23. The output is presented to inverting amplifier U2, the gain of which is controlled by trimmer R20 (model RkP-349 will also include R15 and R18 as shown in Figure 2-6). Q7 and Q8 serve as capacitance multipliers to further filter the supply voltages to U1 and U2.

Photo pickoff, CR3 consists of an LED-phototransistor pair, and serves to generate a signal that synchronizes the Rk-3440 with the chopped radiation. The pickoff is placed such that the chopper blade interrupts the light beam from the LED to the phototransistor as it rotates thereby generating a reference signal equal to the chopping rate. The pickoff also drives the circuit comprised of Q1, Q2, Q3 and Q4. This circuit generates a minute current that is injected into the summing junction of U1 in order to null out the effects of unwanted background radiation. Q4 generates a 0 to +15V square in phase with the pickoff and in turn drives Q1 which produces a 0 to -15V square wave. These two signals are summed at the junction of R3 and R10, adding to zero. The variable DC level from the cancel control circuitry in the Rk-3440 causes either Q2 or Q3 to conduct depending on its polarity. As conduction occurs, some of the signal is subtracted from the summing junction of R3 and R10. This results in a square wave, the polarity and amplitude of which is controlled by the polarity and amplitude of a D. C. voltage.

This square wave causes a small current to flow in R13 and will either add to or subtract from the detector signal.

The Hall effect motor and control electronics is an integral assembly and if trouble arises, should be replaced in its entirety. A ten turn trimpot (accessable by removing the rear plate of the RkP-345) allows adjustment of motor speed and should be set for a 30Hz chopping rate (±0.1%). This should be checked during calibration.

RkP-341

The RkP-341 is similar to the RkP-345 except for a smaller active area (0.1 cm^2) and lower noise level. Since it is designed primarily for the sensitive measurement of irradiance (W/cm^2), no special attempt has been made to control the response uniformity across the active area. This fact should be borne in mind when using the RkP-341 for total power measurement.

RkP-349

The RkP-349 uses a small detector and a 2 inch focal length collecting lens to facilitate low level measurement of power or irradiance as well as the measurement of radiance from targets larger than the probe field-of-view. Two lens materials are available: fused silica (RkP-349V) and ZnSe (RkP-349I). The lens position is adjustable to allow optimization for a range of target distances.

A three position switch is provided to select the appropriate scaling for readout of power (Watts), irradiance (W/cm^2), or radiance (W/cm^2Sr). When measuring either power or irradiance, the readout indication should be divided by 10. For radiance, it should be multiplied by 1000.

3. OPERATING PROCEDURE

3.1 Internal Chopping - To begin measurements, connect the Power Probe to the instrument by way of the 10 pin connector on the rear panel. Select the desired range, place the chopper Int. - Ext. switch in the Int. position. Apply power to the instrument and allow 5 minutes for stabilization.

Place the "Background Null" switch in the Off position and set the "Phase" control to zero. If the environment in which the instrument is to be used has significant air currents, a window should be employed. (See the section on use of windows). Aim the probe at the source to be measured with the source turned off. Turn the averaging time control to the "Fast" position. A reading will be noted that is indicative of a temperature difference between the detector and the detector's field-of-view. The background null switch should be set to the "Cold" position if the sign of the display is negative and to the "Hot" position if it is positive. Adjust the background null vernier control for a zero reading. At least 60uW/cm^2 of the background radiation may be cancelled by this feature. If the background radiation exceeds this level, external chopping should be employed (see "External Chopping"). Energize the source to be measured. The signal present at the "Mixer Output" connector should be viewed on an oscilloscope and the "Phase" control should be adjusted until the waveform shown in paragraph on "External Chopping" is achieved. Alternatively, if an oscilloscope is not available, the "Phase" control should be adjusted for a maximum reading. Select the averaging time consistent with the required response time and the amount of noise present. The time of response (to 99% of reading) for the three positions are as follows:

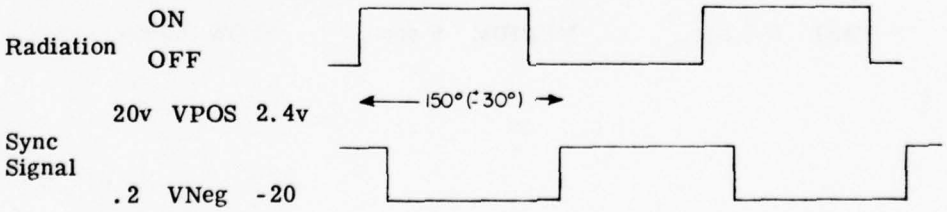
FAST 0.5 sec. MEDIUM 5 sec. SLOW 50 sec.

3.2 External Chopping - Place the "Int.-Ext." switch on the rear panel in the Ext. position. When using the RkP-341 or 345, insert a pencil (eraser end) into the nose cone and move the blade out of the aperture. When using the RkP-349 it may be necessary to remove the probe cover to insure that the chopper is not obscuring the received radiation.

The external chopper (which must have a chopping rate of 30Hz ±.5%) should be placed as close as possible to the source so as to avoid chopping background radiation. The instrument will interpret ALL chopped radiation as signal. The background null is disabled in this mode of operation.

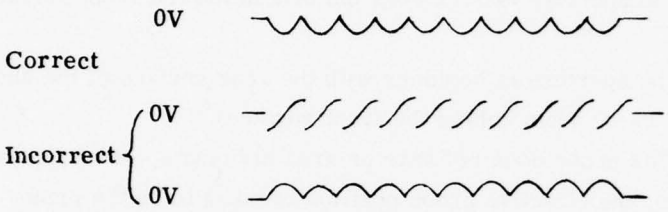
The CTX-430 is designed specifically for use with the Rk-3440. To employ this device, insert its male connector into the 10 pin female connector at the rear of the Rk-3440 and the probe to be used to the female connector of the CTX-430. The chopper has a nominal chopping rate of 30Hz. For best performance it is recommended that the speed adjustment be trimmed at the users location to 30Hz (±.5%). This may be accomplished as follows. View the mixer output with a line-synced oscilloscope allowing five minutes for speed stabilization. Adjust the trimpot located at the lower right side of the motor speed control enclosure until the oscilloscope display is stationary.

When using choppers other than the CTX-430, a signal synchronous with the chopped radiation must be supplied to the Ext. chopper sync BNC connector on the rear panel. The signal should be a square wave with rise and fall times less than 500usec. The amplitude and phase relationship to the chopped radiation should be as follows:



The phase control will provide a certain amount of phase shift in order that the 150° phase lag might be attained. If there is any doubt about the correct phase relationship, the following test may be performed. View the mixer output

on an oscilloscope. The correct phase relationship will be realized when the mixer output is as follows:



When the correct waveform is attained the instrument may begin measurement.

3.3 Display: The instrument display has a full scale reading of 1999. The most significant digit is blanked until it is required. Overrange conditions are indicated by the display of the letters "OF". When a range is selected that is not designed to be used with a given probe the display will indicate "1.888". This feature also serves as a lamp test. The position of the decimal point indicates the maximum irradiance that will be displayed for a given range.

3.4 Window Changing: If the instrument is to be used for measuring low level signals in a windy environment, a window should be employed. To change windows when using an RkP-345 (Serial Numbers less than R88), remove the two screws securing the top cover and lift it off. Slide the window holder from its slot by inserting thumbnail under its lip. Drop in the new window holder and replace cover. The empty window holder provided defines the field of view and should be replaced when a window is not required. Newer models have .75" diameter windows that may be removed by unscrewing the front piece of the nosecone. The window of the RkP-341 probe can be changed by unscrewing the front piece of its nosecone.

3.5 Microphonics: Pyroelectric detectors are intrinsically microphonic. It is therefore recommended that the detector be isolated from ambient vibrations.

3.6 Probe Aperture Position: When measuring irradiance, it is often necessary to know the exact position of the probe area defining aperture. This is given below for each of the three probes:

RkP-341 - The aperture is 2.68 ±0.1 cm behind the flat front surface of the probe.

RkP-345 - The aperture is coplaner with the rear surface of the chopper housing (or 2.02 ±0.1 cm behind the front surface).

RkP-349 - This probe does not have an area defining aperture, as such. For reference, the effective probe position is taken to be the plane corresponding to the outer edge of the front surface of the collecting lens.

3.7 Probe Related Scale Factors:

RkP-345: The RkP-345 has an active area of 1.0 ±0.005 cm^2. The readout indication can thus be interpreted directly as Watts or W/cm^2 depending respectively on whether the radiation distribution is smaller or larger than the detector area.

RkP-341: This probe is intended primarily for irradiance measurements (W/cm^2). If it is used to measure the total power of a radiation beam smaller than the detector area the readout indication should be divided by ten and interpreted as "Watts". Note that care should be exercised in using the RkP-341 for total power measurements since its active area uniformly is not specifically controlled in manufacture.

RkP-349: The RkP-349 is provided with a switch to allow appropriate scaling for the measurement of power, irradiance, or radiance (W/cm^2Sr). When measuring power or irradiance the readout units should be divided by 10. When measuring radiance, they should be multiplied by 1000.

When using the RkP-349 for either power or irradiance measurements it should be noted that the narrow field of view (1^o to 2^o) requires careful

angular positioning of the probe relative to the direction of light propagation. In addition, the lens position must be adjusted to insure that all of the received radiation falls within the detector area. Since the field-of-view at the detector is determined by an internal stop, the irradiance calibration will not be valid if the lens position is optimized for too small a source distance (less than about 2 meters).

Radiance measurement requires that the target area be larger than the probe field-of-view. It is independent of lens position as long as this condition is met. The radiance calibration accuracy is relatively poor (±10%) due to such factors as uncertain lens transmission, black body emissivity, and ambient temperature.

4. CALIBRATION

4.1 Rk-3440 Electrical Calibration

Equipment Required:

1. General purpose oscilloscope
2. Function generator with sine wave and sync outputs
3. Digital multimeter with 0.2% accuracy on AC at 30Hz
4. Frequency counter with period measurement capability

Calibration of Rk-3440: Remove the two Phillips head screws at the lower extreme corners of the rear panel. Slide the top cover off. Check the power supply voltages at the turret terminals at the edge of the power supply. (See Power Supply Fig. 6-3). The voltages should be +15V, -15V +5V within ±100mV.

Zero Adjustment:

Control Settings:

Range Switch	$10W/cm^2$
Window Transmission	Fully Clockwise
Int-Ext Sync	Ext
345-341/349 Selector Switch	345
Averaging Time	Medium

Apply a 30Hz (±0.1%) square wave from the function generator sync output to the sync input BNC connector on the rear panel. The display should indicate 0.00. If it does not, adjust the zero control, R29 for a zero reading.

30Hz Filter Adjustment: Control Settings - As in preceeding section.

Leaving the sync signal connected as in the previous section, apply the 30Hz sine wave to Pin B of the 10 pin detector connector. Set the voltage level at approximately 2.5V RMS. Insure that the sine wave is within 0.1% of 30Hz. View the output of U4 (Pin 6), the 30Hz active filter, with the oscilloscope. Using as much vertical gain as possible, carefully adjust R20 for maximum output.

Sampling Time Adjustment - Leaving the controls set as they were, view the mixer output with the oscilloscope. Adjust the beam position control until the waveform becomes an inverted full wave rectified sine wave as shown in the timing diagram (fig. 2-2). If the control does not have sufficient range parallel C3, a 1μF capacitor, at the left rear of the board with approximately 0.5μF. After the correct waveform is attained, note the meter reading. Switch the averaging time switch to the fast position. The meter reading should settle to the same value. If it does not, adjust R11 until the meter reads the same for both averaging time settings.

Gain Adjustment - Leaving the equipment connected as before, return the averaging time switch to the medium position. Reduce the 30Hz sine wave amplitude to precisely 20mV R.M.S. Turn the range switch to the 200uW/cm^2 position. Adjust the gain control, R9 located at the rear of the range switch, to obtain a reading of approximately 199.9 on the front panel meter.

4.2 Chopper Speed Adjustment (Ref. Figure 2-4)

Before proceeding with the probe optical calibration, the frequency of the internal chopper should be checked. This can be done by attaching an oscilloscope probe to the collector of Q2. The period should be 33.33 ±0.2 msec. To adjust the speed, remove the two Allen head screws retaining the rear plate of the housing. Turn the plate to one side and gently pull the motor speed control board out until the ten turn trimpot is accessible (fig. 2-8). Adjust the trimpot for the correct chopper period. Replace rear plate.

4.3 Standard Optical Calibration (RkP-341 and 345)

In this section we describe the standard calibration performed at Laser Precision. This calibration is referenced to NBS traceable electrical standards by means of an Electrically Calibrated Pyroelectric Radiometer (ECPR). An alternative calibration, based on the use of a standard source, is described in section 4.3.

Calibration of the radiometer probes can be carried out in any appropriately equipped optical metrology facility. However, a calibration service is also available from Laser Precision for those requiring special purpose calibrations or greater accuracy than achievable in their own laboratory.

4.3.1 Required Equipment:

1. Rs-3940 or 3960 ECPR
2. Quartz-halogen lamp or other stable radiation source
3. Digital voltmeter
4. Oscilloscope

4.3.2 Calibration Method:

1. Position the RkP-341 or 345 probe at an appropriate distance from the source to give a reading of 1.5 to 1.9 mW.
2. Translate the probe to insure that the received power does not change significantly (±1%) for movements comparable to the probe aperture diameter.
3. Using an oscilloscope, check the Rk-3440 phase adjustment, as described in section 3.2.
4. Replace the RkP probe with the ECPR detector and measure the received irradiance using the procedure given in IS-394 or 396, as appropriate.
5. Remove the ECPR detector and replace it by the RkP probe, taking care to insure that both the lateral position and the source-detector distance be kept constant to within 2mm.
6. For a given input signal on the 20mW scale, take an arbitrary reading (ie 1.70mW). Switch to 2mW scale. Adjust probe ratio control R23 to DPM reading matching 20mW reading (ie 1.700mW).
7. Adjust the probe gain control R20 to yield a reading consistent with the ECPR measurement on the 2mW scale.
8. Replace the probe cover.

4.4 Calibration from a Standard Source (RkP-341 or 345)

RkP Series Probes can be calibrated by means of a standard source such as an NBS traceable lamp or a black body standard. If a black body or other "weak" source is used, an external chopper should be employed. This should be positioned near the source so as to minimize the effects of background radiation. The procedure outlined below assumes the use of a black body standard.

4.4.1 Required Equipment:

1. Black body standard
2. DVM
3. Oscilloscope

4.4.2 Calibration Method:

1. Chop the radiation with an external chopper as close to the source as possible. The chopping frequency should be 30 ±0.1 Hz. The chopper sync signal should have a duty cycle of 50 ±1%.
2. Position the probe approximately 40cm from the black body with its axis aligned precisely with the black body aperture. Measure the distance from the black body aperture to the probe area defining aperture to an accuracy of ±1mm (see section 3.6).
3. Calculate the irradiance at the probe aperture, using the expression:

$$P_D = \frac{A_{BB}\sigma(T_{BB}^4 - T_D^4)}{\pi r^2}$$

Where: P_D is the power density at the detector surface
A_{BB} is the black body aperture area in cm^2

σ is Boltzman's constant = $5.6 \times 10^{-12} W/cm^2 \cdot {}^oK^4$
T_{BB} is the black body temperature in ^oK
T_D is the ambient temperature in ^oK
R is the aperture to detector distance in cm.

4. Check to see that the internal chopper blade is completely out of the detector field-of-view.
5. Using the oscilloscope to monitor the mixer output, adjust the Rk-3440 phase control as described in section 3.2.
6. Adjust the probe gain control (R 20) to yield a reading consistent with the irradiance calculated in step 3.
7. Attach the DVM between ground and the input to the Rk-3440 DPM (pin A1 of the DPM connector).
8. Adjust the probe ratio control (R23) for 1/10 voltage when the range switch is turned from the 2mW to the 20mW scale. If the black body irradiance is not sufficient to allow this adjustment to be accomplished accurately, any stable but not necessarily calibrated source can be used.
9. Replace the probe cover.

4.5 RkP-349 Spot Probe Calibration

4.5.1 Power and Irradiance

The RkP-349 power and irradiance calibrations can be performed using the methods of either section 4.3 or 4.4, as long as appropriate measures are taken to either correct for or avoid the wavelength limitations of the probe lens (fused silica for the RkP-349V and ZnSe for the RkP-349 I).

At Laser Precision an ECPR is used as a standard. As a result, a calibrated source is not necessary. When calibrating the RkP-349V, the source is an unfiltered Quartz halogen lamp. For the RkP-349I, the same lamp is used, but the short wave radiation is blocked by a germanium sheet. This yields a radiation spectrum restricted to the 1.8 to 3.0 micron region.

Procedure

1. Position the quartz halogen source at least 3 meters from the intended detector position. Insert the germanium sheet if a ZnSe lens is being used in the probe (RkP-349I).
2. Measure the irradiance with the ECPR.
3. Replace the ECPR detector with the RkP-349, taking care to maintain a constant source-detector distance. The probe position is taken as the edge of the lens front surface.
4. Turn the probe function switch to the irradiance position.
5. Carefully adjust the x and y angular orientation of the probe, and the lens focus, for a maximum signal.
6. Adjust the Rk-3440 phase control as described in section 3.2.
7. Adjust the probe ratio control as described in section 4.3 steps 6 and 7.
8. Adjust the irradiance trimmer to yield a reading consistent with the ECPR measurement. This is the center trimmer of the three mounted on the probe circuit board.
9. Turn the probe function switch to the power position.
10. Move the RkP-349 slightly further from the source and place a precision aperture in the position previously occupied by the ECPR detector aperture. Calculate the total power passing through this aperture. Note that the optimum aperture would be a 0.5 cm^2 ECPR aperture.
11. Adjust the power trimmer to give the calculated reading. This is the top trimmer of the three in the probe.

NOTE: The irradiance calibration is only valid when the lens position is set to correspond to a distant source. The power calibration is independent of lens position as long as the received power is completely focussed into the detector area and the illuminated area does not exceed the effective probe area for the given lens position.

4.5.2 Radiance Calibration

This calibration should be performed after the probe ratio control has been properly set as described in section 4.2 steps 6 and 7. The only additional equipment needed is a black body source with an area greater than the instrument field-of-view.

RkP-349I Procedure

1. Position the black body source and probe so that the source area exceeds the instrument FOV. The lens can be left in the distant source position used above.
2. Set the black body temperature for the highest convenient value.
3. Using a radiation slide rule or a table of black body emittance values, determine the total emittance for the given temperature.
4. Determine the fraction of the total emittance falling beyond the sharp 18 micron ZnSe cut-off and subtract this from the total.
5. Determine the black body emittance corresponding to the temperature of the probe (ambient) and subtract this from the result of step 4 to give the effective emittance.

6. Calculate the effective radiance, $N = W/\pi$ where W is the effective emittance of step 5.

7. With the probe switch in the radiance position, adjust the radiance trimmer to give a reading corresponding to the value of step 6. This is the bottom trimmer of the three in the probe.

NOTE: Due to the uncertainties of black body surface temperature and lens transmission, we assign a relatively wide uncertainty (±10%) to the radiance calibrations performed at Laser Precision.

RkP-349V Procedure

The RkP-349V uses a fused silica lens. Since the transmission of this lens does not substantially overlap the spectrum of a practical black body, a direct radiance calibration would be quite difficult. It is thus best to regard the use of the RkP-349V for radiance measurements as a relative procedure. At Laser Precision, an approximate calibration is arrived at by first calibrating the probe with a ZnSe lens and then reducing the radiance trimmer adjustment enough to correct for the higher transmission of the fused silica lens.

5. PERFORMANCE OPTIONS AND ACCESSORIES

5.1 Option RB - BCD Output

A fully parallel BCD output is provided with this option. The outputs are TTL compatible and will drive one unit load. (Source 400μA, and sink 1.6 mA.).

BCD Connections

PIN #	FUNTION	PIN #	FUNCTION
1	End of Count	13	NC
2	Off Scale	14	1 Out
3	D. P. 100	15	2 Out
4	D. P. 10	16	4 Out
5	D. P. 1	17	8 Out
6	NC	18	10 Out
7	NC	19	20 Out
8	NC	20	40 Out
9	NC	21	80 Out
10	1000 Out	22	100 Out
11	Ground	23	200 Out
12	NC	24	400 Out
		25	800 Out

6. Rk-3442 POWER RATIOMETER SYSTEM

6.1 Introduction

The Rk-3442 System consists of 4 components. These are: 2 standard radiometer probes, RkP-341, 345, or 349, one modified Rk-3440 Power Readout, and one Rk-3441 Ratiometer readout.

The modified Rk-3440 operates exactly as described in the Instruction Manual for the standard Rk-3440. The modification is simply the addition of a sample and hold buffer for the direct output. This removes the output integrator ripple, which would otherwise show up in the Rk-3441 ratio indication. The modification is shown in schematic LP-72027 (Figure 6-1).

The Rk-3441 is also a modified Rk-3440 and operates in the non-ratio mode exactly as in the manual except that the BNC connector marked "DIRECT" functions as a signal input for ratioing. The direct output signal is not available on this unit. The Rk-3441 modifications are shown in schematic LP-72028 (Figure 6-2).

6.2 Ratio Measurement Operation

Connect the probes to their respective readouts and connect a BNC cable between the connectors marked "DIRECT" on the rear panels of the two readouts.

To measure power, set the ratio button on the Rk-3441 to the "out" position (no green light showing). The controls on the two units should then be set appropriately to result in on-scale readings. To measure a ratio, push the "RATIO" button so that the green light shows. At this time the Rk-3441 readout displays the ratio of the reading which would have been indicated on the Rk-3441 to that which still appears on the Rk-3440. Thus, if the 3441 reads 6.0mw/cm^2 and the 3440 reads 9.0mw/cm^2, the reading in the ratio mode should be 0.667. Note that the decimal point indicated in the ratio measurement assumes that the two readouts are on the same range. If this is not the case, an appropriate decade scale factor must be applied. For example, if the 3440 reads 4.00w/cm^2 and the 3441 reads .400w/cm^2, the ratio reading will be 1.000, whereas the actual ratio is 0.100.

There are a few restrictions on the operation of the ratio module. First, both readings must be positive. Second, the ratio readout is valid from .000 to 1.050. Higher readings are not accurate. Third, the accuracy of the ratio improves with the size of the input signals. Thus, it is best to choose ranges where the power indications are between 200 and 1999.

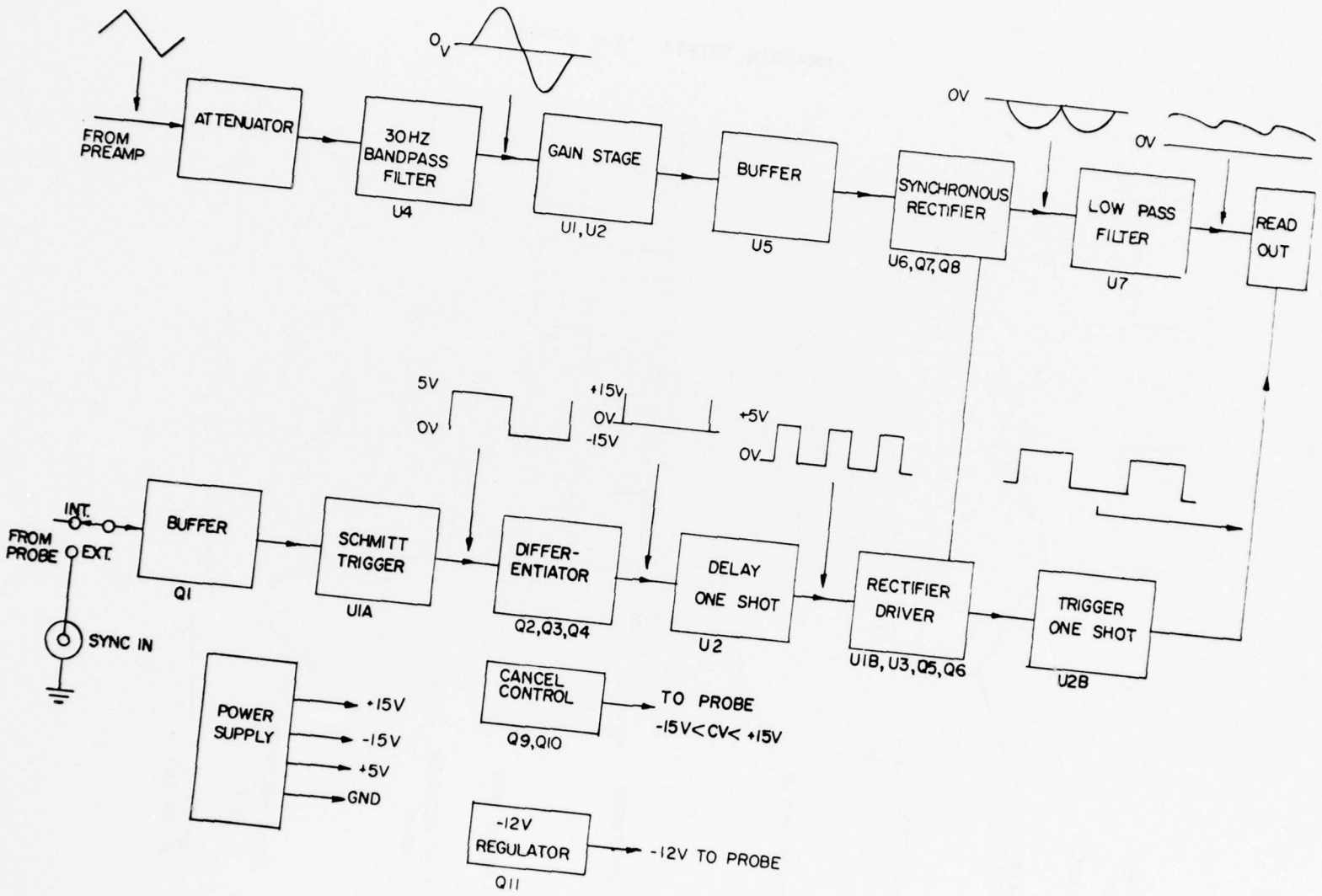


Figure 2-1. Rk-3440 Block Diagram.

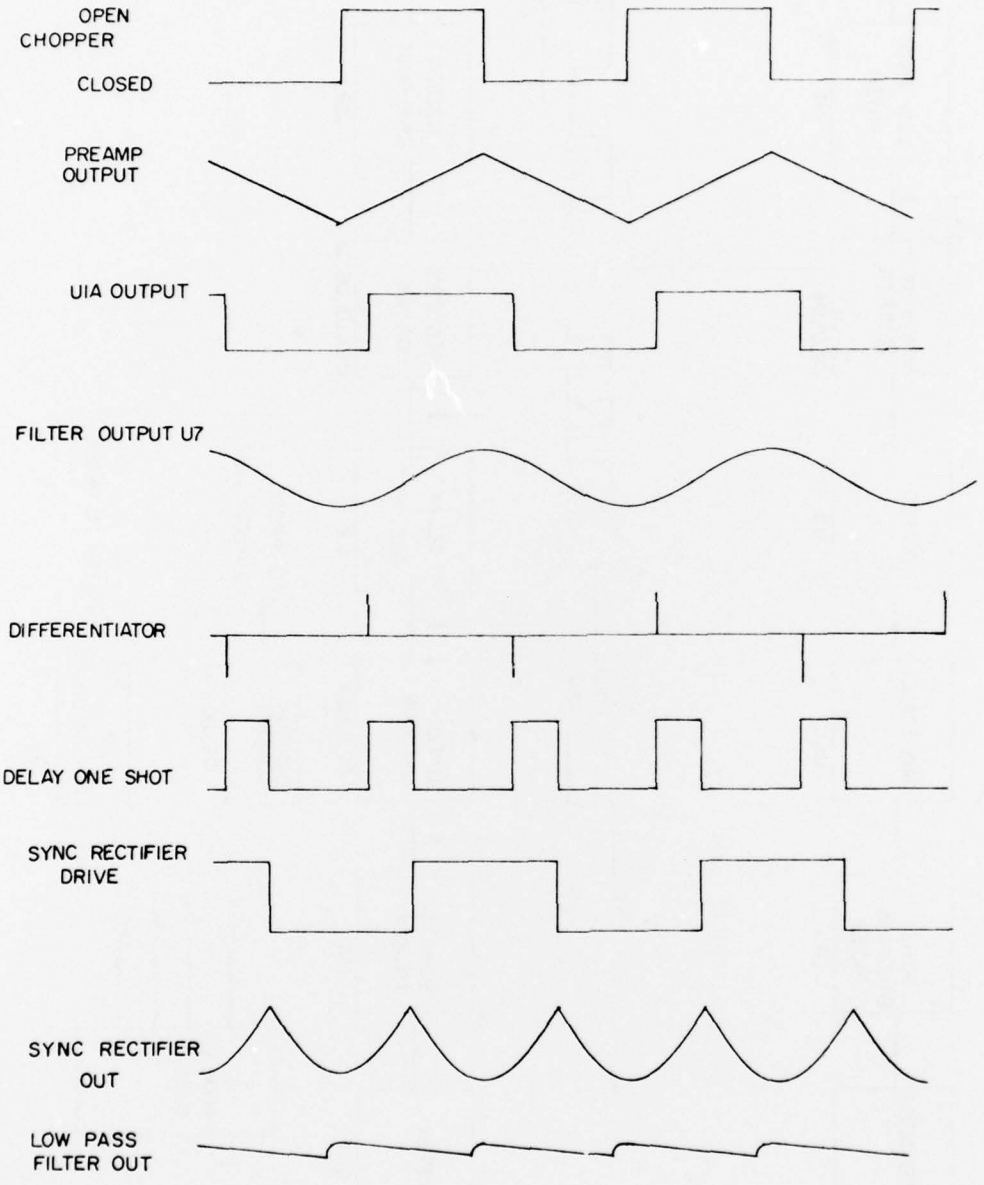
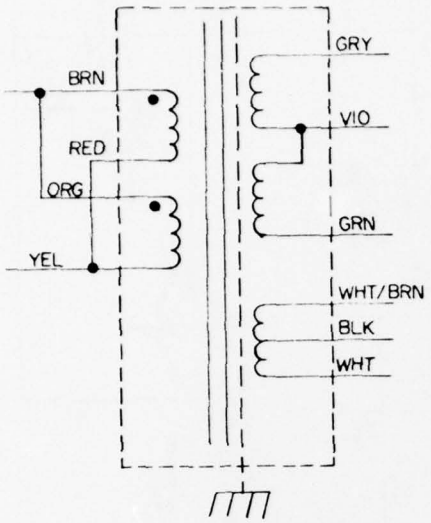
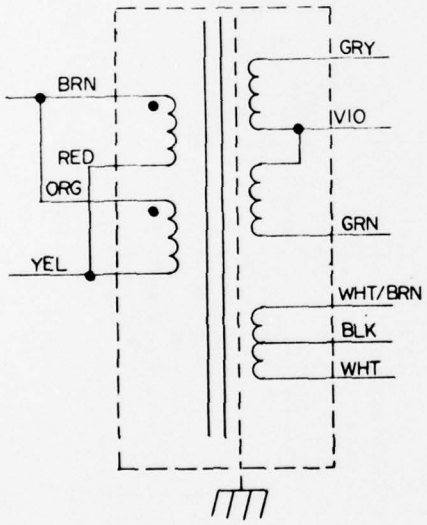


Figure 2-2. Timing Diagram.





NOTES:
1. $V_{1,2}$ NOM = $V_{3,4}$ NOM = 115V, 50/60 HZ (LINE)
2. $V_{5,7}$ NOM = 36 VRMS, AT 450 MA AC
   BALANCED WINDING WITH V6 CENTER TAP
3. $V_{8,10}$ NOM = 16.5 VRMS, AT 1.2 A AC
   BALANCED WINDING WITH V9 CENTER TAP
4. VOLTAGE TOLERANCE IS ± 3% AT F.L.
5. REGULATION IS 10% FROM N.L. TO F.L.

Figure 2-3. Power Supply Primary Connections.

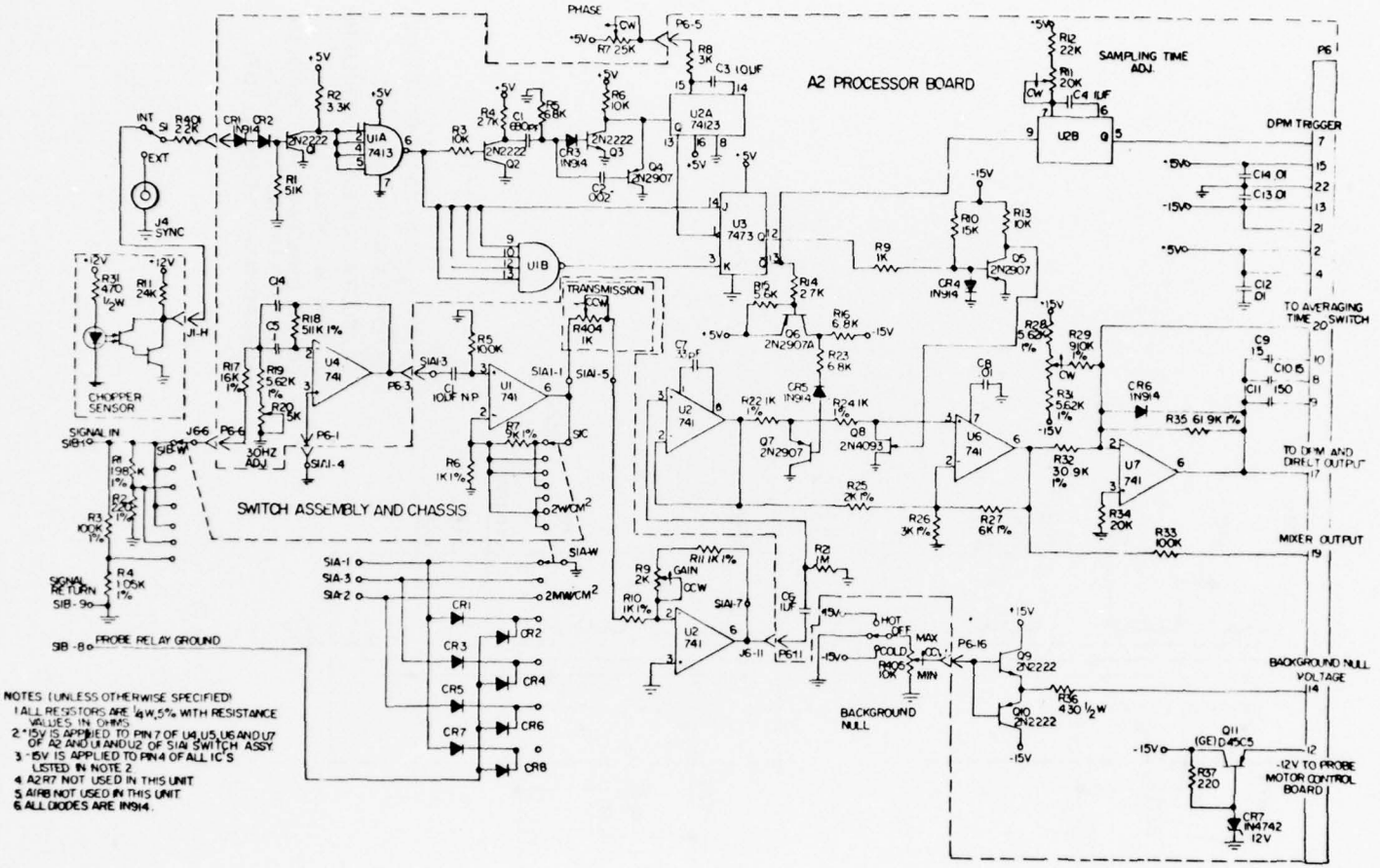
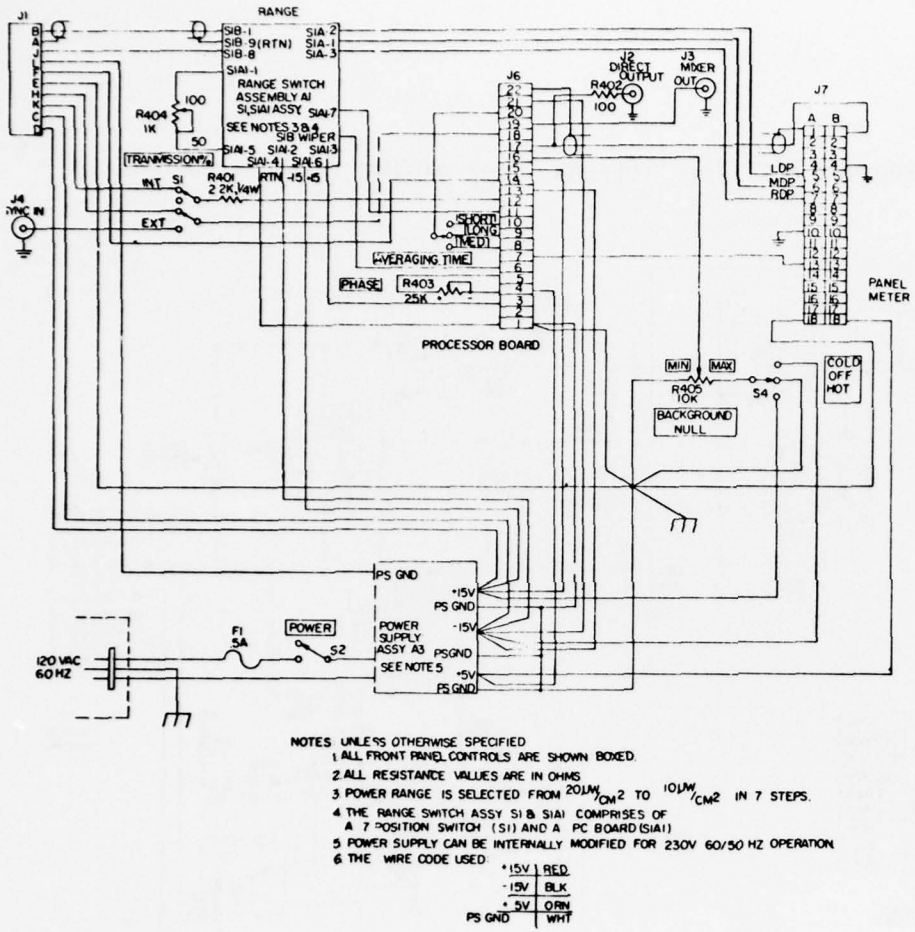


Figure 2-4. Rk-3440 Signal Processing Circuitry and Switch Assembly.



TO

J6A8	1	EOC STATUS
J6A9	2	OVERLOAD SCALE
A5	3	DECIMAL POINT 1
A6	4	DECIMAL POINT 10
A7	5	DECIMAL POINT 100
	6	
	7	
	8	
	9	
A15	10	1000 OUT
	11	
	12	
	13	
J6B5	14	BIT 1
J6B6	15	BIT 2
J6B7	16	BIT 4
J6B8	17	BIT 8
J6B9	18	BIT 10
J6B10	19	BIT 20
J6B11	20	BIT 40
J6B12	21	BIT 80
J6B13	22	BIT 100
J6B14	23	BIT 200
J6B15	24	BIT 400
J6B16	25	BIT 800

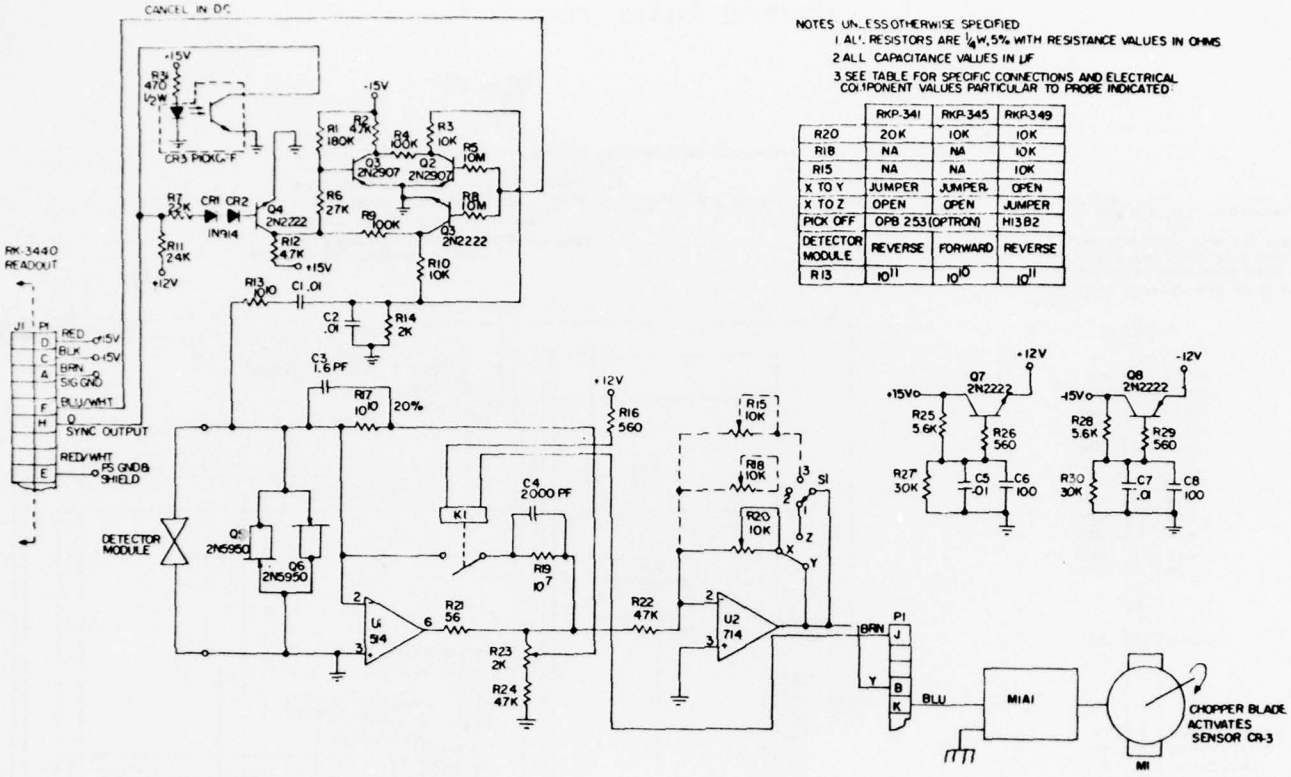
J5
BCD OUTPUT

NOTE
1 USED IN OPTION RB MOUNTED ON REAR PANEL
2 "HIGH" - DURING CONVERSION PERIOD OUTPUT INVALID, DISPLAY BLANKED
"LOW" - CONVERSION COMPLETE OUTPUT VALID 2 TTL LOADS
I/O DATA IS BCD/TTL INFORMATION, POSITIVE LOGIC

NOTES: UNLESS OTHERWISE SPECIFIED
1. ALL FRONT PANEL CONTROLS ARE SHOWN BOXED.
2. ALL RESISTANCE VALUES ARE IN OHMS
3. POWER RANGE IS SELECTED FROM $20\mu W/CM^2$ TO $10\mu W/CM^2$ IN 7 STEPS.
4. THE RANGE SWITCH ASSY S1 & SIA1 COMPRISES OF A 7 POSITION SWITCH (S1) AND A PC BOARD (SIA1)
5. POWER SUPPLY CAN BE INTERNALLY MODIFIED FOR 230V 60/50 HZ OPERATION
6. THE WIRE CODE USED:

+15V	RED
-15V	BLK
+5V	ORN
PS GND	WHT

Figure 2-5. Wiring Diagram.



	RKP-341	RKP-345	RKP-349
R20	20K	10K	10K
R18	NA	NA	10K
R15	NA	NA	10K
X TO Y	JUMPER	JUMPER	OPEN
X TO Z	OPEN	OPEN	JUMPER
PICK OFF	OPB 253 (OPTRON)		HI3B2
DETECTOR MODULE	REVERSE	FORWARD	REVERSE
R13	10^{11}	10^{10}	10^{11}

Figure 2-6. RkP-341, 345, 349 Preamplifier.

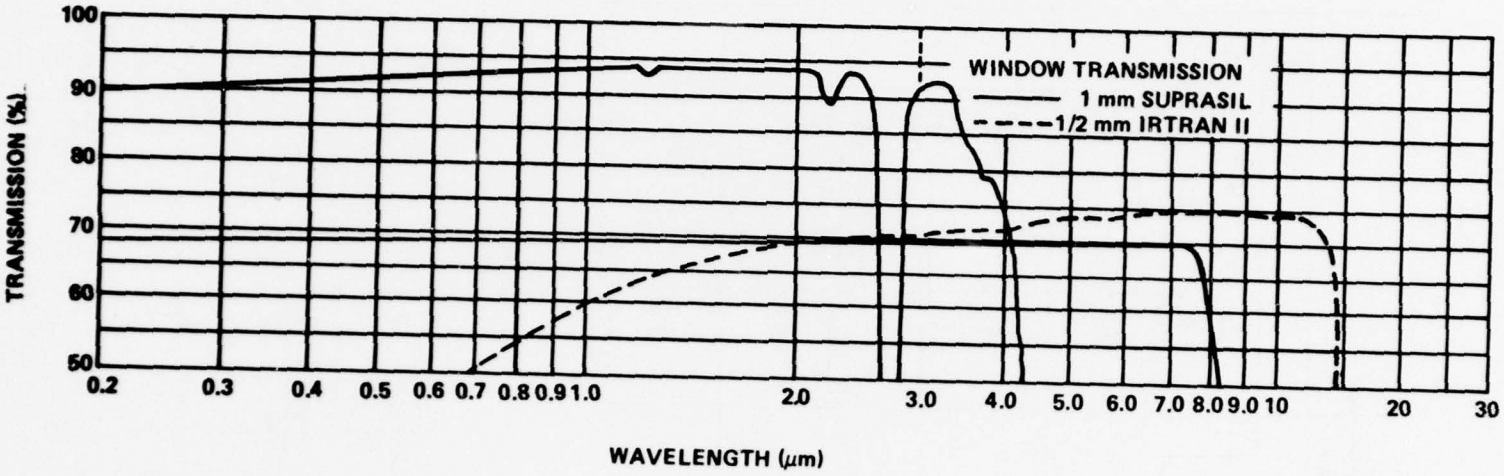


Figure 2-7. Window Transmission.

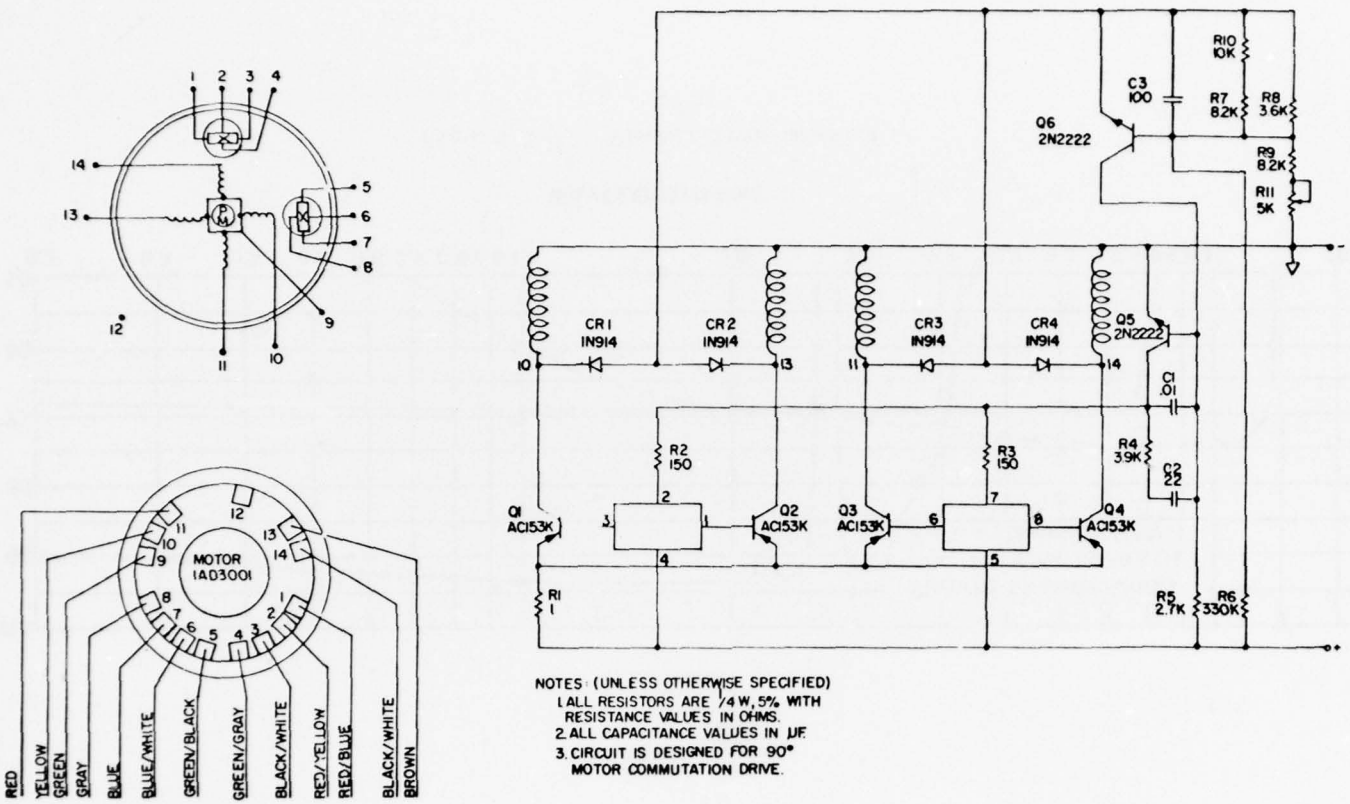
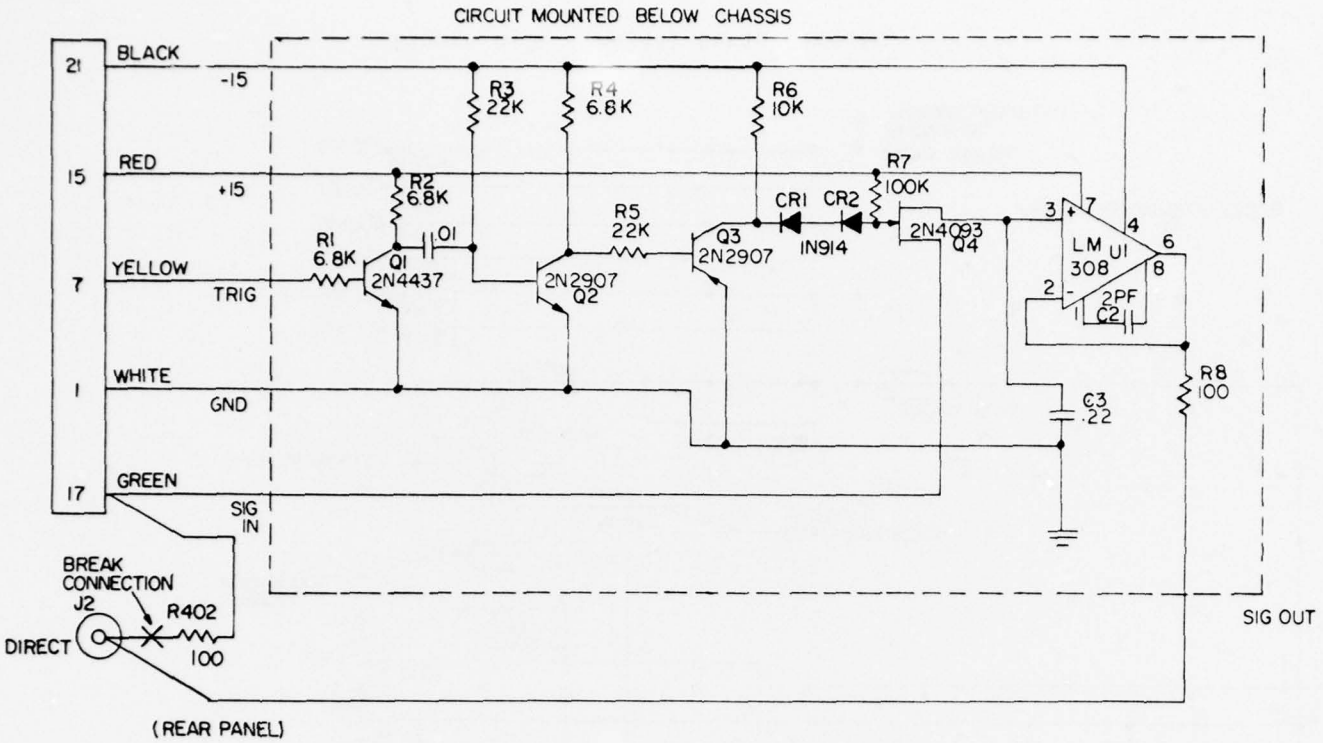


Figure 2-8. Motor Drive Circuit.



NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL RESISTANCE VALUES IN OHMS.
2. ALL CAPACITANCE VALUES IN μF.
3. MODIFICATIONS TO RK 3440 READOUT TO MAKE IT COMPATIBLE WITH RK 3441 RADIOMETER.

Figure 6-1. Rk-3440 Option 01.

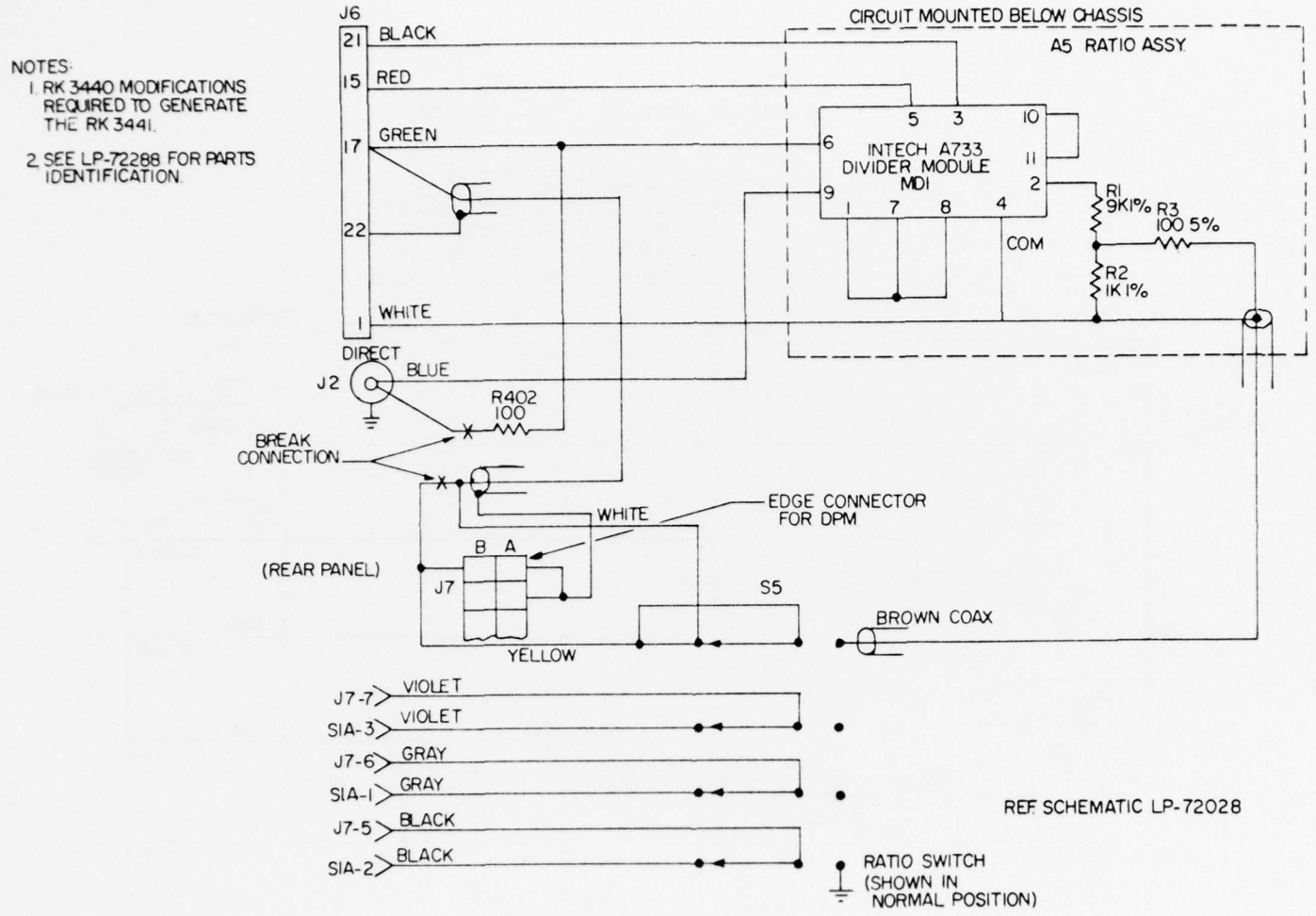
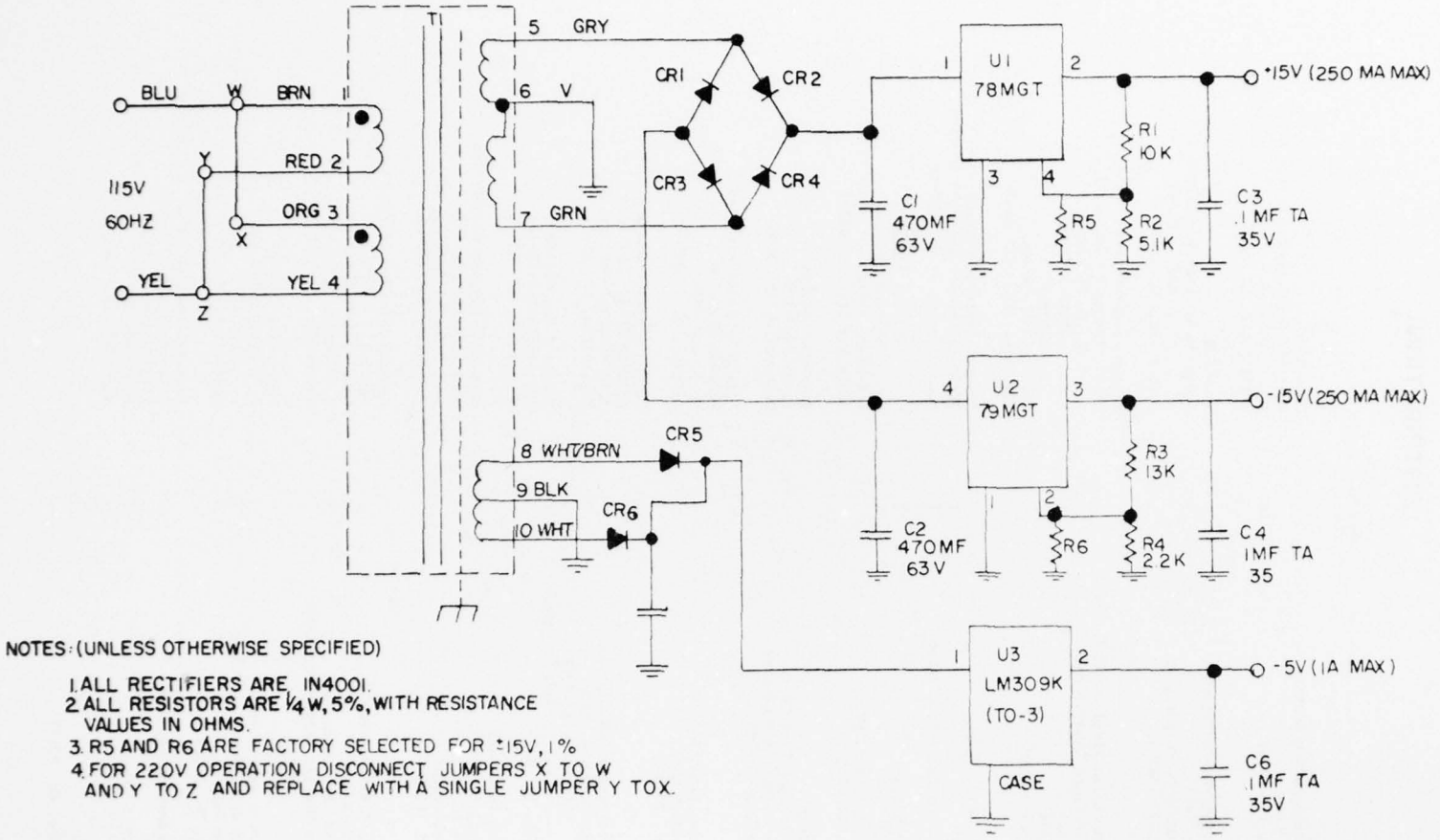


Figure 6-2. Rk-3441 Ratio Circuit.



NOTES: (UNLESS OTHERWISE SPECIFIED)

1. ALL RECTIFIERS ARE IN4001.
2. ALL RESISTORS ARE ¼ W, 5%, WITH RESISTANCE VALUES IN OHMS.
3. R5 AND R6 ARE FACTORY SELECTED FOR ±15V, 1%
4. FOR 220V OPERATION DISCONNECT JUMPERS X TO W AND Y TO Z AND REPLACE WITH A SINGLE JUMPER Y TO X.

Figure 6.3. Power Supply Schematic.

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